VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ
BRNO UNIVERSITY OF TECHNOLOGY

FAKULTA STAVEBNÍ
ÚSTAV VODNÍHO HOSPODÁŘSTVÍ OBCÍ

FACULTY OF CIVIL ENGINEERING
INSTITUTE OF MUNICIPAL WATER MANAGEMENT

MODELOVÝ VÝZKUM ÚČINNOSTI SEPARAČNÍCH TECHNOLOGIÍ ÚPRAVY VODY

THE EFFICIENCY OF WATER TREATMENT SEPARATION PROCESSES – MODEL RESEARCH

DIPLOMOVÁ PRÁCE
MASTER´S THESIS

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Podklady a literatura

[1] TUHOVČÁK, L. a kol.: Vodárenství. Elektronická studijní opora. Brno: VUT v Brně, 2006.
[2] Degrémont Suez. Water Treatment Handbook. Vydání sedmé. Degrémont, 2007. 1718 s. ISBN 978-2-7430-0970-0.
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Zásady pro vypracování

Diplomantka provede modelový výzkum účinnosti separačních technologií za podmínek dle pokynů vedoucího práce. Část diplomové práce bude zpracována v rámci studijního pobytu na Oulu University of Applied Sciences.

Předepsané přílohy

Licenční smlouva o zveřejňování vysokoškolských kvalifikačních prací

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Ing. Tomáš Kučera, Ph.D.
Vedoucí diplomové práce

ABSTRAKTY A KLÍČOVÁ SLOVA

Abstrakt:

Cílem práce bylo provést modelový výzkum účinnosti procesu flotace rozpuštěným vzduchem při úpravě vody. V rámci série experimentů byla vyhodnocována účinnost vyjádřená pomocí zákalu a UV absorbance při různých podmínkách. Na používaném fyzikálním modelu flotační nádrže byly simulovány různé provozní podmínky procesu flotace, a to např. nastavováním různé polohy trysek pro přívod vzduchu, změnou doby zdržení v separační zóně flotační nádrže.
V první části (THEORY) je popsán flotační proces z teoretického hlediska. V další části jsou uvedeny dva příklady úpraven vody využívající flotační technologie-jedna je v Oulu (Finsko), druhá v České Republice (Mostiště).
Poslední část je zaměřena na samotný výzkum v laboratoři - je popsán technologický proces úpravy, poté jsou uvedeny vstupní hodnoty, výpočty, měření, vyhodnocení výsledků a na závěr vzájemné srovnání účinností odstranění zákalu a UV absorbance při různých podmínkách.

Klíčová slova:

Flotace pod tlakem rozpuštěným vzduchem, Separační proces, Úprava vody, Úpravna vody, Zákal, Účinnost

Abstract:

The goal of this research was to recognize dissolved air flotation efficiency by the help of turbidity and UV absorbance removal for different conditions. As different conditions are meant the efficiency for different baffle position, different detention time in separation zone and checking results with adding chemicals compared to results without adding chemicals.
First part, named THEORY, describes flotation process theoretically. In the next part are imaged two examples of purification water treatment plants which used DAF process concretely in Oulu and in Czech Republic named Mostiště. Last part is focused on model research in laboratory of Oulu University contains described whole technological water treatment process, input data values, calculation, measuring, results evaluations and at the end are introduced results as comparison turbidity and UV absorbance removal for different conditions.

Keywords:

Dissolved air flotation, Separation process, Water treatment, Water purification treatment plant (or water treatment plant), Turbidity, Efficiency

BIBLIOGRAFICKÁ CITACE

VAŠALOVSKÁ, Petra. *Modelový výzkum účinnosti separačních technologií úpravy vody*. Brno, 2011. 84 s. Diplomová práce. Vysoké učení technické v Brně, Fakulta stavební, Ústav vodního hospodářství obcí. Vedoucí práce Ing. Tomáš Kučera, Ph.D.

Prohlášení:

Prohlašuji, že jsem diplomovou práci zpracoval(a) samostatně, a že jsem uvedl(a) všechny použité, informační zdroje.

V Brně dne 6.1.2012

……
podpis autora

PODĚKOVÁNÍ

V úvodu této práce bych především chtěla poděkovat panu Ing. Kučerovi, Ph.D za podporu při mém výjezdu do zahraničí, za ochotu a odborné konzultace v průběhu vypracovávání této práce, dále za cenné rady a připomínky a za možnost se na něj kdykoliv obrátit o radu či pomoc.

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OBSAH

1 INTRODUCTION

This Master´s thesis is focused on model research on the efficiency of dissolved air flotation water treatment separation process. Flotation is technological process used in water treatment. It´s the reverse process of sedimentation, removing suspended particles which are lighter than surrounding water by gravitational rising [2].

At the beginning is described flotation process theoretically. It contains ranking in conventional water treatment process, flotation history, types of flotation processes etc. Further is theoretical part more closely focused on dissolved air flotation (DAF) – types of flotation tanks, dissolved air flotation efficiency, factors influencing DAF efficiency, etc. At the end of this part is analysed comparison between sedimentation and DAF.

In the next are imaged two examples of purification water treatment plants which use DAF process. One of them takes place in the city of Oulu (Finland) and the second one, named Mostiště, is the only one purification water treatment plant with flotation process in Czech Republic.

Last part and the most important part of this thesis as well, is focused on model research in laboratory of Oulu University. Firstly is described whole technological water treatment process updated with photos, after that are shown input data values, calculation, measuring, results evaluations and at the end are introduced results as comparison turbidity and UV absorbance removal for different conditions.

2 THEORY

The choice of water treatment process is very difficult problem which is depended on many factors influencing final water quality. It´s effort to select process by the need to produce acceptable finished water quality at the most attractive overall cost. Water treatment process selection depends on [1]:

- Water resource quality
- Desired finished water quality
- Reliability of process equipment
- Operational requirements and personnel capabilities
- Flexibility in dealing with changing water quality and equipment malfunctions
- Available space for construction of treatment facilities
- Waste disposal constraints
- Capital and operating costs (including chemical availability)

Water treatment processes can be grouped into the water treatment scheme according to their general function.

2.1 WATER TREATMENT SCHEME

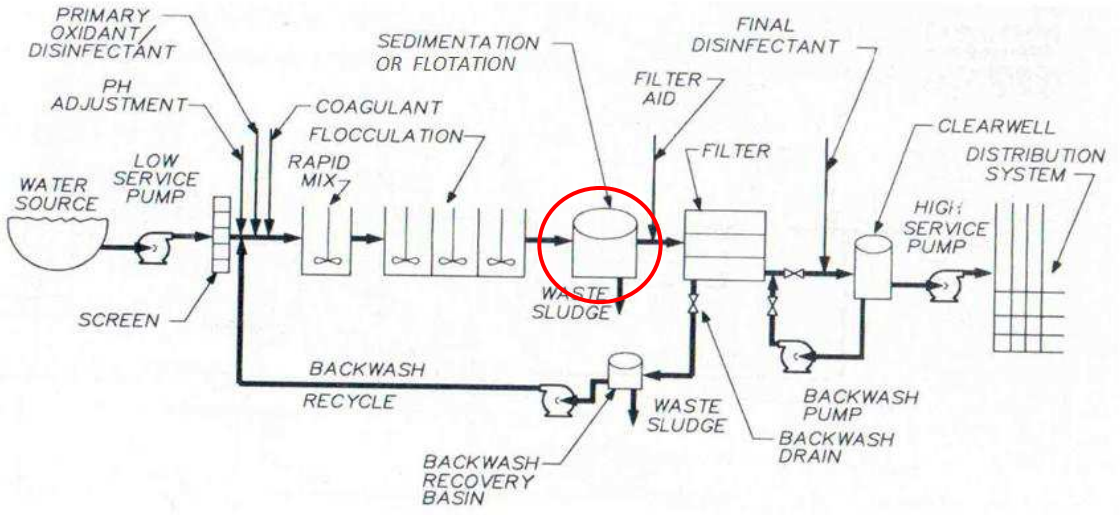


Fig. 2.1 Conventional water treatment [1]

The basic treatment processes include coagulation, flocculation and sedimentation prior to filtration and at least disinfection to annul microbiological organisms [1].

Flotation is ranked as first separation process in two-stage separation water treatment. It´s take place before filtration to remove bigger particles and helps saving filters.

2.2 FLOTATION PROCESS

2.2.1 INTRODUCTION

Flotation is technological process used in water treatment. It´s the reverse process of sedimentation, removing suspended particles which are lighter than surrounding water by gravitational rising [2]. The air microbubbles attach themselves to the particles (resp.flocs) and together float to the water surface. Then are these complexes removed by sludge collectors [1]. Thereby are getting lower the solids concentration, or load, on granular filters. As a result, filters are saved and their working live is prolonged [3].

In water treatment is flotation sorted as first step within two-stage water treatment. This process is not recommended as only one separation process although its efficiency is quite high [3].

2.2.2 HISTORY

Over 2000 years ago, the ancient Greeks used a flotation process to separate desired minerals from the gangue (from crushed ore) by force of surface tension. In 1860, was patented a process in which oil was used for separation minerals from the gangue [1].

In 1905 was developed froth flotation by Salman, Picard and Ballot. It was entrained air and small amount of oil was added. The first froth flotation equipment was developed in 1910 by T. Hoover – it was not so different from the equipment used today. In 1940 was introduced foam flotation where air bubbles were formed through submerged porous diffusers. The two processes, froth and foam flotation, are generally known as dispersed-air flotation and are mainly used in the mineral industry [1].

In 1904 Elmore suggested using electrolysis to produce gas bubbles for flotation. This process is at the time called electrolytic flotation. He also invented the dissolved-air

(vacuum) flotation (DAF) process, whereby air bubbles are produced by applying a vacuum to the liquid.

Flotation became in water treatment technology used in the late 1960s in several countries, such as in Canada, USA, Great Britain, Australia and European Union countries. In water treatment, it has become accepted as an alternative to sedimentation. Flotation is employed mainly for the treatment of nutrient-rich reservoir waters that may contain heavy algal blooms, and for low-turbidity, allow alkalinity, colored water. These types of water are difficult to treat by sedimentation [1].

2.2.3 TYPES OF FLOTATION PROCESSES

According to methods of produced gas bubbles is flotation process splitted into different types of flotation processes. These are electrolytic flotation, dispersed-air flotation, and dissolved-air flotation

Electrolytic Flotation. The basis of electroflotation is the generation of bubbles of hydrogen and oxygen in a dilute aqueous solution by passing a DC current between two electrodes. Generated bubble size is very small [1].

Dispersed-Air Flotation. Two different types of dispersed-air flotation are used: foam flotation and froth flotation. Both of them are unsuitable for water treatment because of their large bubble size [1].

Dissolved-Air flotation: In this process bubbles are produced by the reduction in pressure of a water stream saturated with air. There are three types of DAF: Vacuum flotation, microflotation and pressure flotation. Of these three, pressure flotation is the most widely used. It´s based on that the air is dissolved in water under pressure. Three pressure DAF processes can be used: full-flow, split-flow and recycle flow pressure flotation. For water treatment, most appropriate system is recycle-flow pressure flotation. It consists in that part of the clarified effluent is recycled, pressurized and saturated with air. The pressurized recycle water is introduced to the flotation tank through a pressure-release device and is mixed with the flocculated water. In pressure-release device, is the pressure reduced to atmospheric pressure and the air in the form of fine bubbles (with diameter 10-100 μm) is released. The air bubbles attach themselves to the flocs, and the aggregations float to the surface. The clarified water is taken from the bottom of the flotation tank [1].

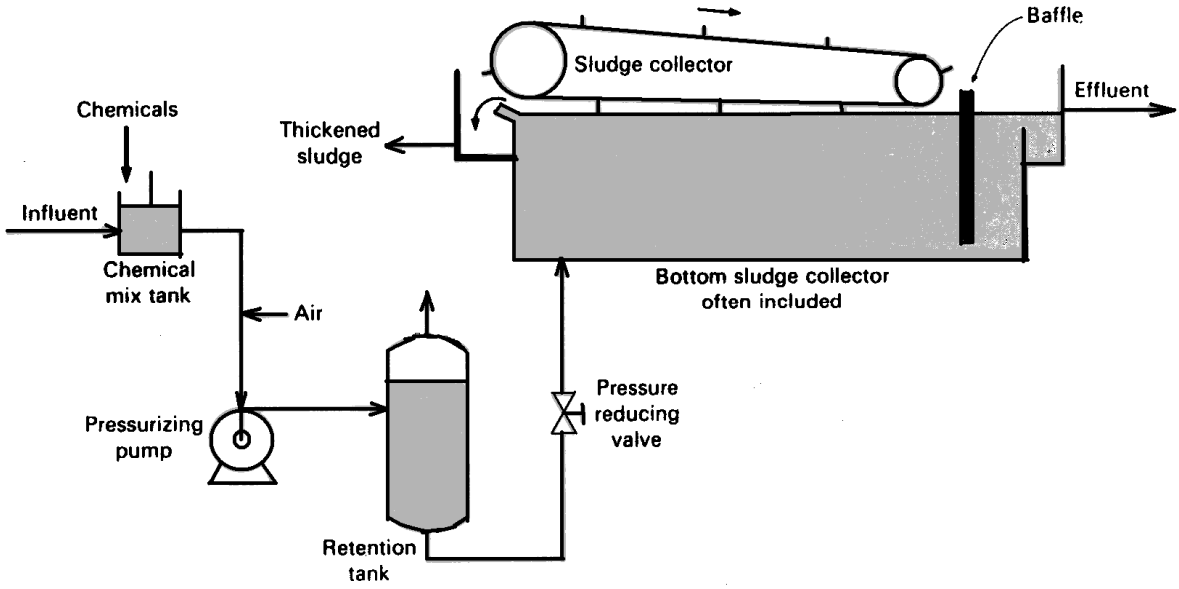


Fig. 2.2 Dissolved air flotation [2]

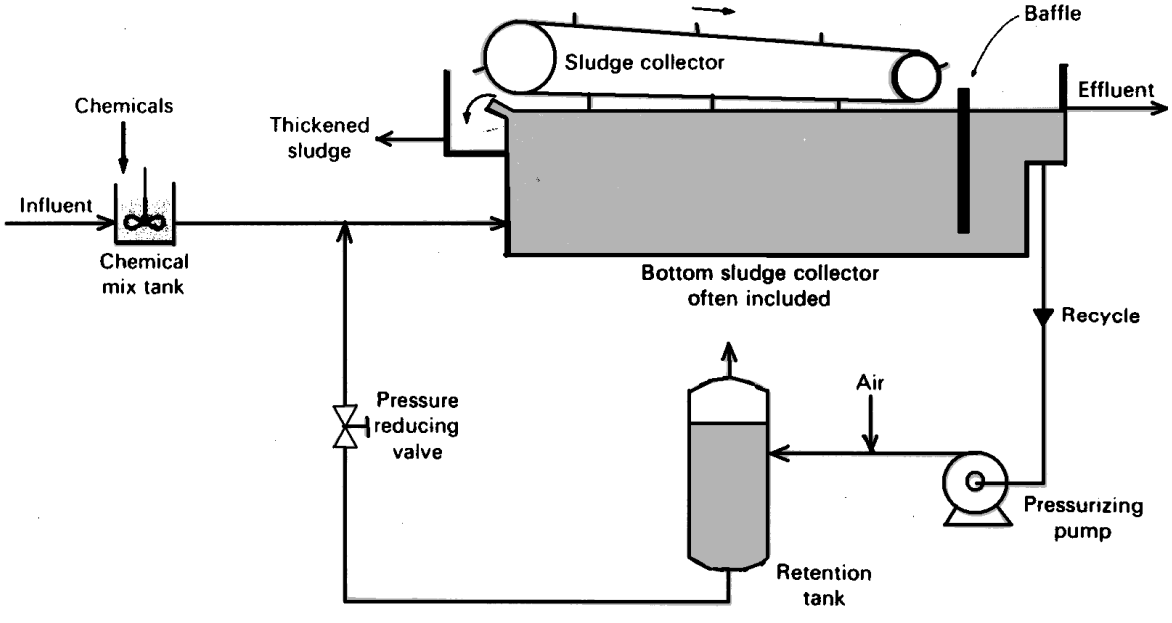


Fig. 2.3 Dissolved air flotation with recirculation [2]

In the retention tank of Fig. 2.2., the raw water stays only for a few minutes – it is limited by the amount of air going into solution. In practice only 50 – 70% of saturation concentration can be obtained [2].

The retention tank of Fig. 2.3 deals with only 5 – 15% of the flow. It means that 95% of saturation concentration can be obtained. Therefore the retention tank can be constructed much smaller [2]. Its construction is shown in Fig. 2.4

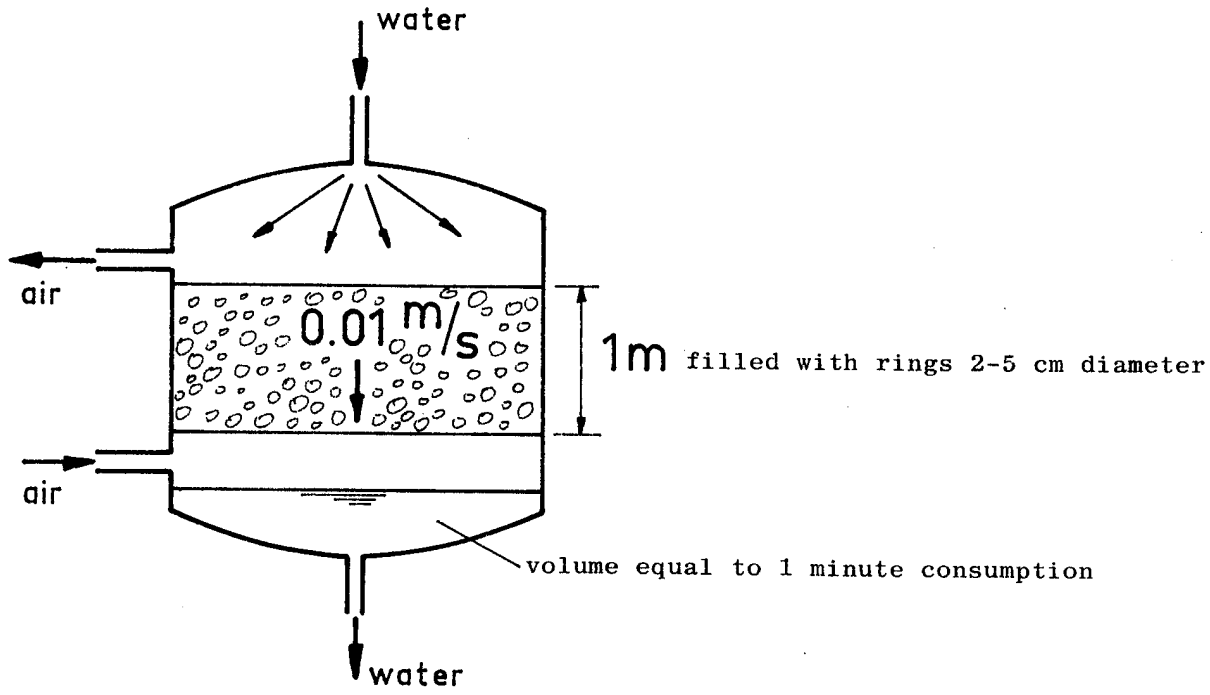


Fig. 2.4 Retention tank to be applied in DAF with recirculation [2]

2.3 DISSOLVED AIR FLOTATION

To achieve high efficiency, particles and natural color present in the water must be firstly coagulated and flocculated to the form of bubble-floc aggregations [4].

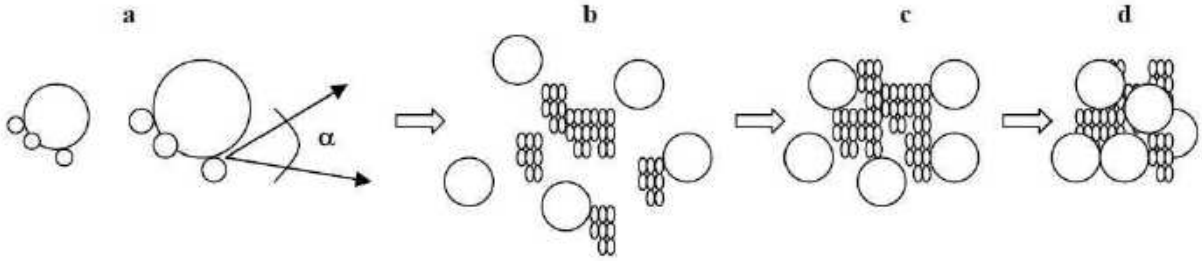


Fig. 2.5 Bubble-floc aggregations formation in pressure flotation [4]

a) fixation air bubble on element surface (the angle ɑ should be between 0° - 90°), b), c), d) formation bubble-floc aggregations floating to the surface [4].

The solubility of air in water follows by Henrys law and increases linearly in depend on pressure and with temperature the solubility linearly decreases. This is shown in the Table 2.1. In this case is counted with atmospheric conditions [2].

Tab. 2.1 Air solubility-temperature characteristic [4]

temperature [°C]	0	5	10	15	20	25	30
solubility [l/m^3]	28,6	25,8	23,3	21,5	19,9	18,7	17,7

In practice, air requirements are variable between 2 and 20 liters/m^3 of water to be treated [2].

2.3.1 MECHANISM OF FLOTATION

Floatable bubble-floc aggregations could be form by any of three distinct mechanisms: entrapment of bubbles within a condensing network of floc particles, growth of bubbles from nuclei within the floc and attachment of bubbles to floc during collision [1].

2.3.2 USE OF FLOTATION

Flotation unlike sedimentation can be used for purifying surface water low in absorbance and high in capacity of organic and humic substances. Only in waters very low in dissolved organic matter will flotation efficiency be reduced. It is also suitable for removing fimbriae and cyanobacterias from eutrophic water [4].

In Fig. 2.6. is introduced the table, how is possible to make a decision of the suitable separation process. The zone close to axis „Y“ – called „Chlorophyl a“ is important for us. And because humic substances forms aggregations with properties of a solubility similar to organisms aggregations, is possible to put in axis „Y“ values like CHSK or color instead of „Chlorophyll a“, as well [4].

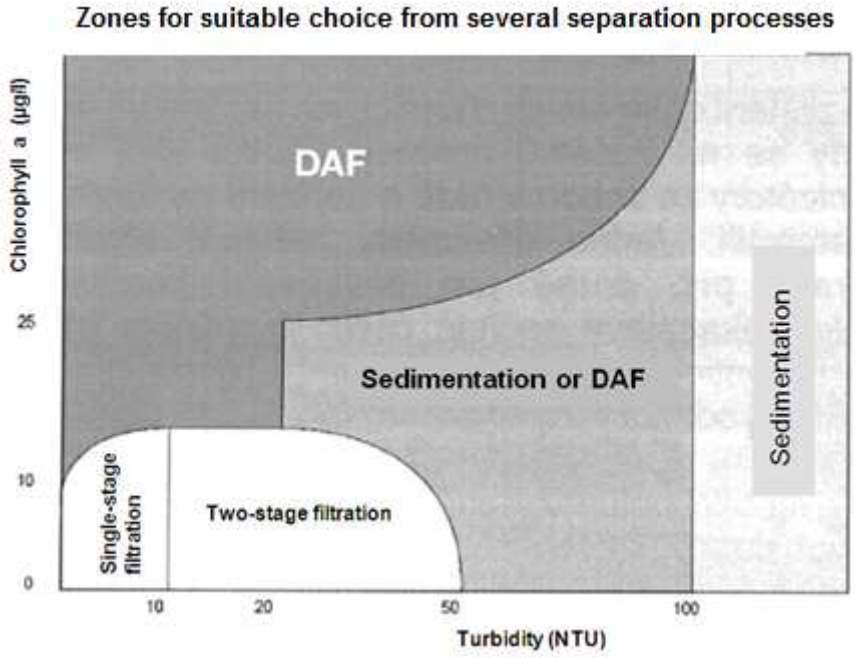


Fig. 2.6 Zones for suitable choice from several separation processes [4]

2.3.3 FLOTATION TANK

Separation process takes place in flotation tank which is divided into several parts. Dissolved-air flotation tanks have two zones and functions (are shown in Fig. 2.7). Into first zone, called contact zone, is coming raw water containing impurities. The purpose of contact zone is to provide contact opportunities between floc particles and bubbles leading to attachment and formation of particle-bubble aggregations with densities less than water. In this zone originates big amount of bubbles of size about 10 – 100 µm. This zone is also called „white water zone“, because of the white turbidity, incurred by microbubbles on the surface.

In the second zone, separation, or clarification, occurs as particle-bubble aggregations rise to the surface. Here is made up compact sludge layer which is removed by sludge collector away. Model of the clarification zone is similar to sedimentation in that Stokes´ law-type expression where are used to describe the rise velocity of the particle-bubble aggregations.

Two approached models have been used to describe collision among bubbles and particles in the contact zone. The first one use a heterogeneous flocculation model that describes collisions among bubbles and particles and the second consider the white water of air bubbles in the contact zone to be much like a filter blanket and model the bubbles as collectors of particles [1].

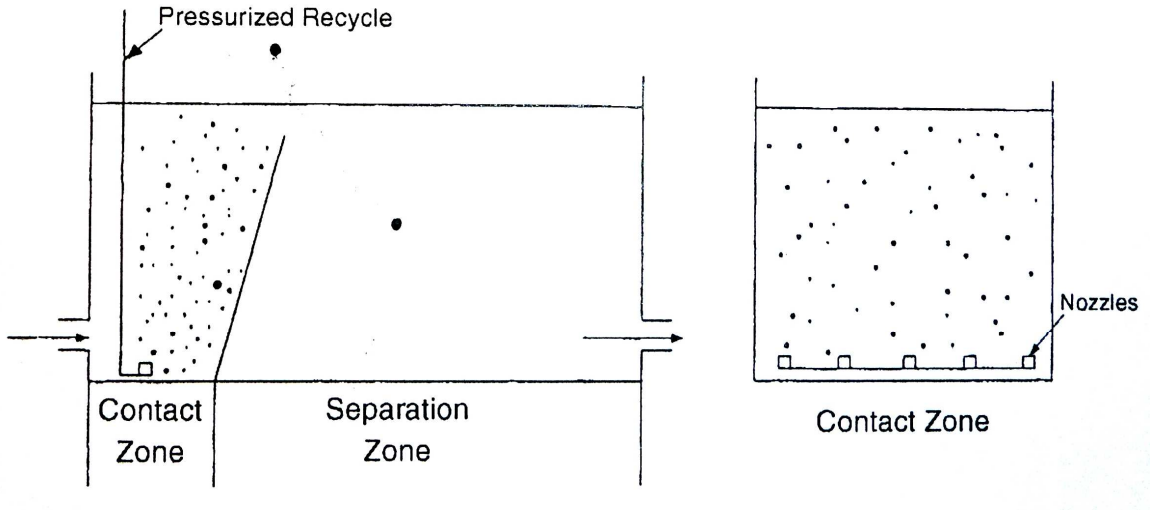


Fig. 2.7 Scheme of a flotation tank showing contact and separation zones [1]

2.3.4 BUBBLE VOLUME AND NUMBER CONCENTRATION

The mass concentration (C_b) of air released is obtained from the following equation [1].

$$Cb = \frac{(C_r - C_{fl})}{1+r} * r \qquad (2.1)$$

where: C_r ... the mass concentration of air in the recycle flow [mg/L]

C_{fl} ... the mass concentration of air in the floc tank effluent [mg/L]

r ... is the recycle ratio expressed on a fractional basis [-]

C_{air} ...is computed from Henry´s law expression [mg/L]

$$p = K_H \cdot C_{air} \qquad (2.2)$$

where: p ... pressure of the air [kPa]

C_{air} ... concentration of air dissolved in water [mg/L]

K_H ... Henry´s law constant [kPa/mg.L^{-1}].

Equation 2.1 assumes that the air in the water leaving the flocculation tank is at saturation.

Separation Zone. The floc particle-bubble aggregate rise velocity can be calculated from Stokes´ law expression [1]

$$v_{pb} = \frac{g(\rho_w - \rho_{pb})d_{pb}^2}{18\mu} \tag{2.3}$$

where v_{pb} ... the rise velocity of the floc particle-bubble aggregations [m/h]

g ... gravitational constant of acceleration [m/s^2]

ρ_w ... density of water [kg/m^3]

ρ_{pb} ... density of the floc particle-bubble aggregations [kg/m^3]

d_{pb} ... diameter of the floc particle-bubble aggregations

μ ... absolute viscosity

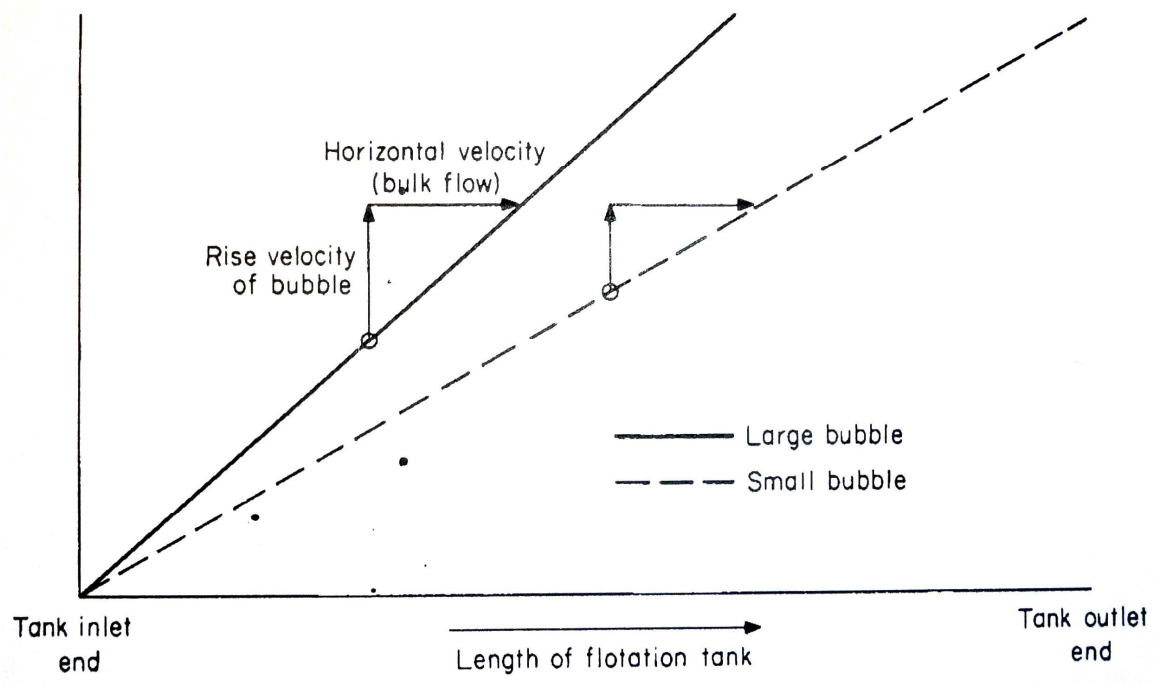


Fig. 2.8 Effect of bubble size on flotation tank size [1]

2.3.5 TYPES OF FLOTATION TANKS

Circular Tanks. Are used mainly in small flotation plants treating wastewater or for sludge thickening applications that require no preflocculation prior to flotation [1].

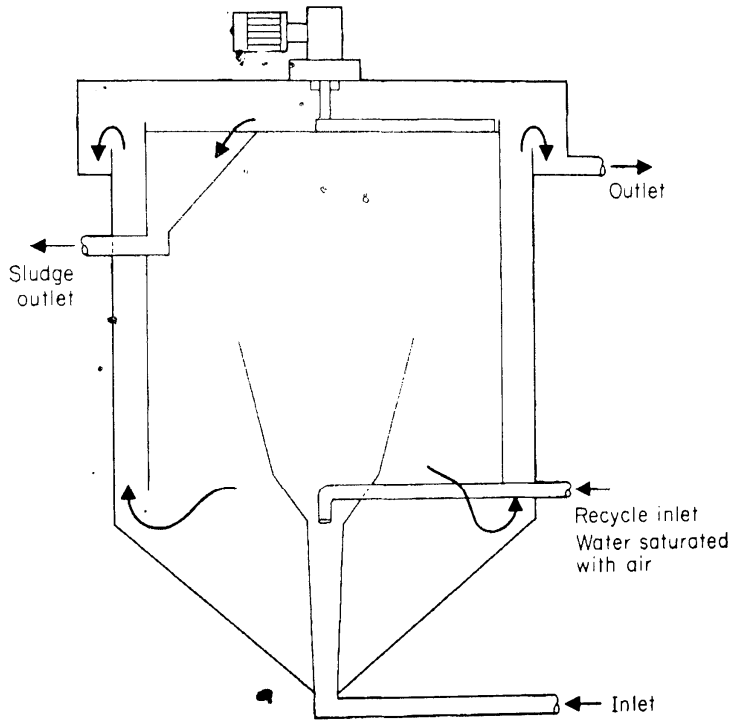
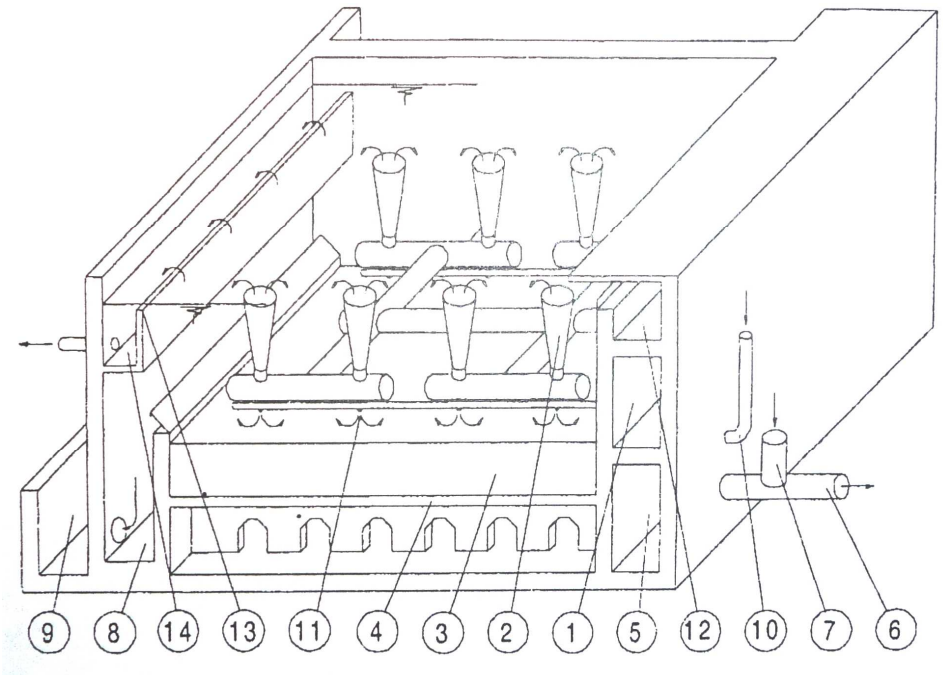


Fig. 2.9 Schematic diagram of a circural tank [1]

Rectangular Tanks. Rectangular flotation tanks offer advantages in terms of scale-up, simple design, easy introduction of flocculated water, easy float removal and relatively small area requirement. Flotation tanks are typically designed with a depth of approximately 1.5 m and hydraulic load between 8 and 12 m/h (depending on water treated). The nominal retention time in the flotation tank is between 5 and 15 minutes. Treated water should be withdrawn preferably via a full-width weir [1].

Countercurrent Flotation. The basic design of DAF has some analogy to horizontal-flow sedimentation, where the flocculated water is entered to one end on a tank. Here is mixed with dissolved air, followed by separation in a horizontal dimension. Because flotation is mainly in the vertical dimension, then flow through the flotation tank should be the same [1].



1 - INLET DUCT

2 – INLET DISTRIBUTION CONES

3 – FILTER MEDIA

4 – FILTER FLOOR

5 – OUTLET & UPWASH DUCT

8 – WASHOUT BAY

9 – WASHOUT CHANNEL

10 – AIR INLET

11 – AIR DISTRIBUTION NOZZLES

12 – FLUSHING CHANNEL

13 – SCUM WEIR

14 – SCUM CHANNEL

Fig. 2.10 Typical arrangement of a COCODAF unit (countercurrent flotation) [1]

Combined Flotation and Filtration. The combination of flotation and filtration was promoted in Sweden. A rapid gravity sand or anthracite-sand filter is situated in the lower section of the flotation tank. This concept has the advantage of providing an extremely compact plant. The flotation rate of the plant is limited by the filtration rate that can be achieved. The tank depth of a flotation-filtration plant tends to be deeper, approximately 2.5 m, to accommodate the filter bed and underdrain system. The compactness of this system makes it particularly suitable for package plants [1].

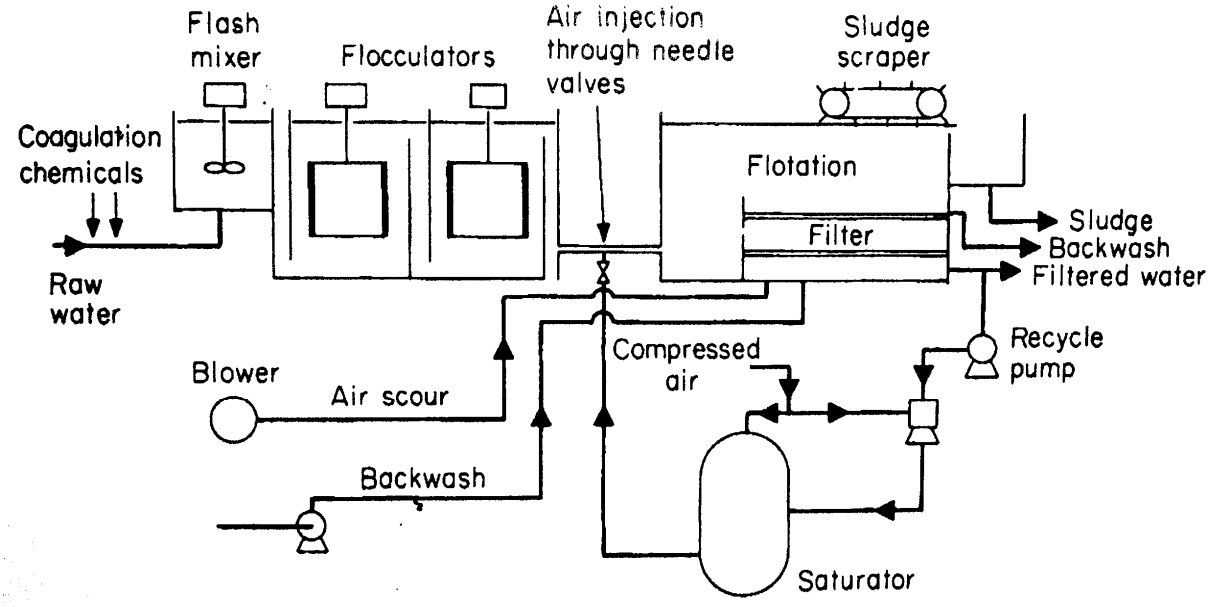


Fig. 2.11 Schematic diagram of combined flotation-filtration plant [1]

2.3.6 DISSOLVED-AIR FLOTATION EFFICIENCY

For the surface water is flotation separation ability high. Organisms and microorganisms removing is vary between 98 – 99.9 % of removal for the hard polluted water. From amount of organisms about 400 org/ml, was reached after flotation process amount of organisms from 0 – 6 org/ml [3].

Iron removal from raw water is vary between 96 – 98 %. Concentration of remaining iron in flotation outlet is usually between 0,18 – 0,35 mg/l. The efficiency of organic particles removal ($CHSK_{Mn}$) is flown about 70 %, as well as in case of hardly eutrophic water [3].

2.3.7 FACTORS INFLUENCING DAF EFFICIENCY

Coagulation. Collisions occur between bubbles and particles in the contact zone of the flotation tank. To achieve favorable conditions for attachment of bubbles with particles requires good coagulation pretreatment. The chemicals used as coagulants have two roles in flotation: 1) to produce floc particles with reduced surface charge, and 2) to produce particles that are hydrophobic [1].

Flocculation. Before coagulated impurities can be removed successfully flotation, flocculation into larger agglomerates (floc) is required. Flocculation for flotation has a

different objective than for sedimentation. Sedimentation needs floc particles from 100 µm and larger, flotation is effective with smaller floc particles [1].

Flocculation time. The flocculation time required differs with type of raw water being treated, coagulant used, and water temperature. For turbid and warm waters is usual flocculation time less than 10 minutes. For soft, colored water using aluminium sulphate when the water is close to freezing, a flocculation time is approximately 20 minutes [1].

Degree of agitation. This factor is also very important for efficient flocculation. Agitation is usually provided by a slow moving. The degree of can be expressed by the *mean velocity gradient, G*. The optimum G value for flocculation is about 70 s^{-1} [1].

Other factors influencing DAF efficiency. To them belong follows:

Hydraulic flocculation – an alternative approach to mechanical flocculation

Quantity of air required for flotation – depends on saturator pressure or the amount of recycle

Air-release devices – different types of pressure-release devices are employed, from nozzles and needle valves to simple gate valves

Float removal – float can be removed continuously or intermittently

Effect of air-solids ratio on float

Influence of source water on float characteristics [1].

2.3.8 FLOAT REMOVAL

The sludge that accumulates on the flotation tank surface is called float. It can be removed either continuously or intermittently by flooding or mechanical scraping. The most widely used mechanical float removal devices are of two types: 1) part- or full- length scrapers usually with rubber or brush blades that travel over the tank surface and push the float over the beach into the collection channel, and 2) beach scrapers that consist of a number of rubber blades rotating over the beach [1].

The beach scrappers, especially if operated continuously, have the advantage of reducing the danger of float breakup during the removal process. Beach scrapers are also of simpler construction compared with full-length scrapers [1].

2.3.9 SEDIMENTATION AND DAF CONFRONTATION

Flotation is several times more effectively compared to sedimentation. DAF efficiency depends on several factors (described above). It´s obvious, that attachment of microbubble with high-quality prepared floc is more effectively than sedimentation [3].

There is no need in flotation process to use any weighting materials or any other auxiliary flocculants unlike sedimentation. For flotation is also need less area. Compared to sedimentation is the flotation area 1/5 – 1/10 of sedimentation area [3].

DAF efficiency is not immediately depended on flocs size prepared by coagulation and flocculation. These parameters are necessary for sedimentation, for flotation play smaller role. Thereby is possible to decrease detention time in flocculation tank [3].

DAF efficiency is influenced by the quality of raw water less than in other technologies. The effect of flotation decreases slowly [3].

But as was mentioned above, flotation process is not in all cases suitable separation process in water treatment. The choice which process is the best of all is very difficult and depends on many factors – from quality of raw and purified water to economy aspects.

3 EXAMPLES OF WATER PURIFICATION TREATMENT PLANT WITH FLOTATION

3.1 WATER PURIFICATION IN CITY OF OULU

Drinking water used in Oulu is purified from surface water of the Oulujoki river. The purification process takes place in two purification plants of Hinta and Kurkelanranta. In both water purification plants is purified about 9,8 million cubic meters of drinking water per year [8].

Fig. 3.1 Tank tower in Oulu [8]

3.1.1 CIRCULATION OF WATER

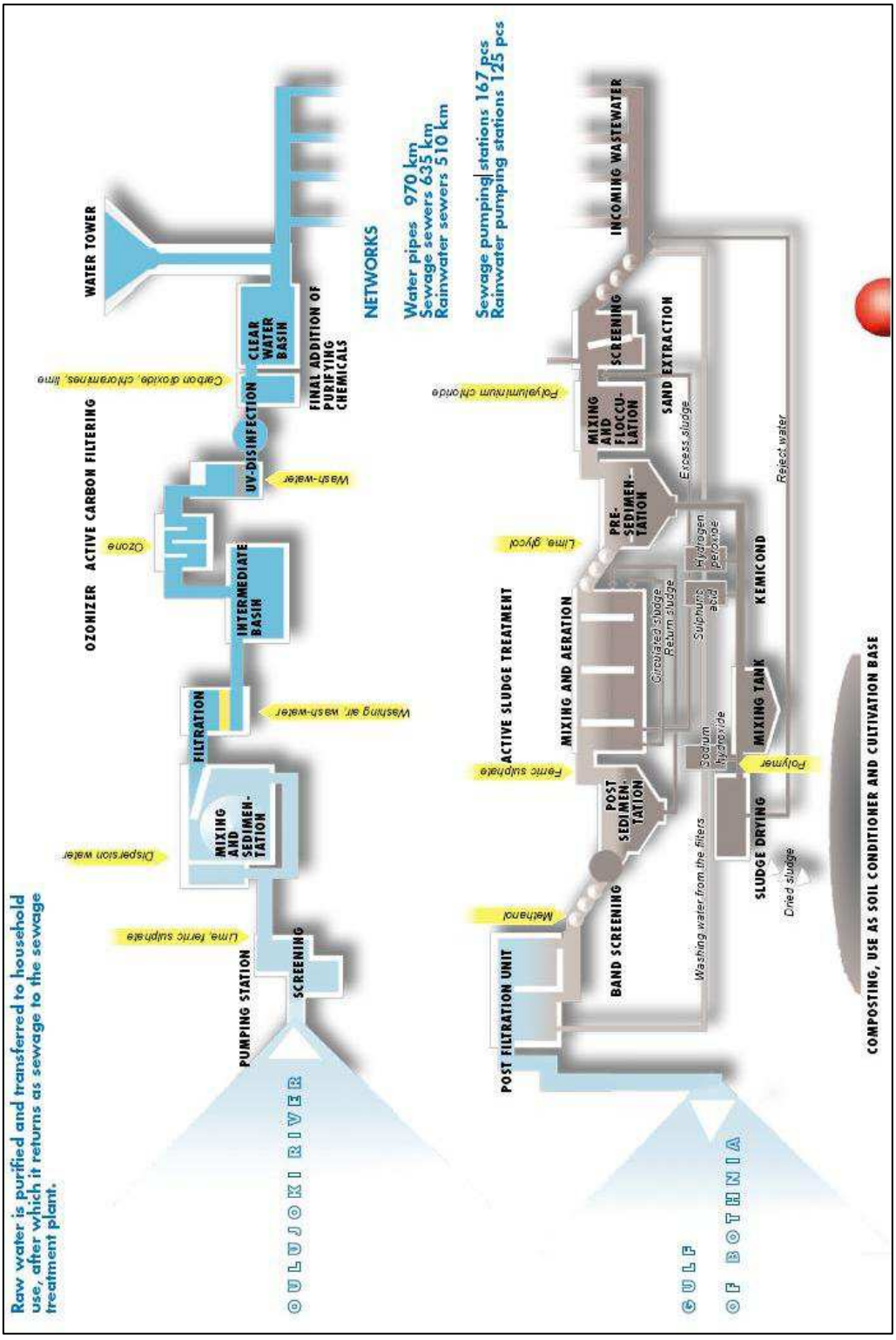


Fig. 3.2 Circulation of water in Oulu [8]

Raw water is purified and transfered to household use, after which it returns as sewage to the wastewater treatment plant

3.1.2 WATER PURIFICATION PLANT

Drinking water in Oulu is purified in two purification plants of Hintta and Kurkelanranta. Both water purification plants have very effective processes:

- Precipitation of impurities in raw water with ferric sulphate
- Settling with flotation
- Sand filtration
- Ozonization
- Active carbon filtration
- Disinfection with sodium hypochloride and ammoniumchloride
- Residual treatment with carbon dioxide and hydrated lime
- UV-disinfection [8]

Water quality:

The quality of drinking water is good, thanks to efficient purification methods and the ability to react to changes in raw water quality by the help of automatic and continuous monitoring.

Water quality is most commonly presented with the $KMnO_4$ number, called permanganate number, which illustrates the amount of organic matter e.g. humus in water. The $KMnO_4$ number was measured less than 20 mg/l. This value is according to legislation [8].

An operational laboratory:

Water quality is controlled in the laboratory which has facilities both for drinking water analyses and waste water analyses, as well. The laboratory controls the purified water of both drinking water plants. It´s also controls the incoming and outgoing waste water and the intermediate forms of the process waste waters for the operational purposes of the plant [8].

3.1.3 WATER TREATMENT PLANT SCHEME

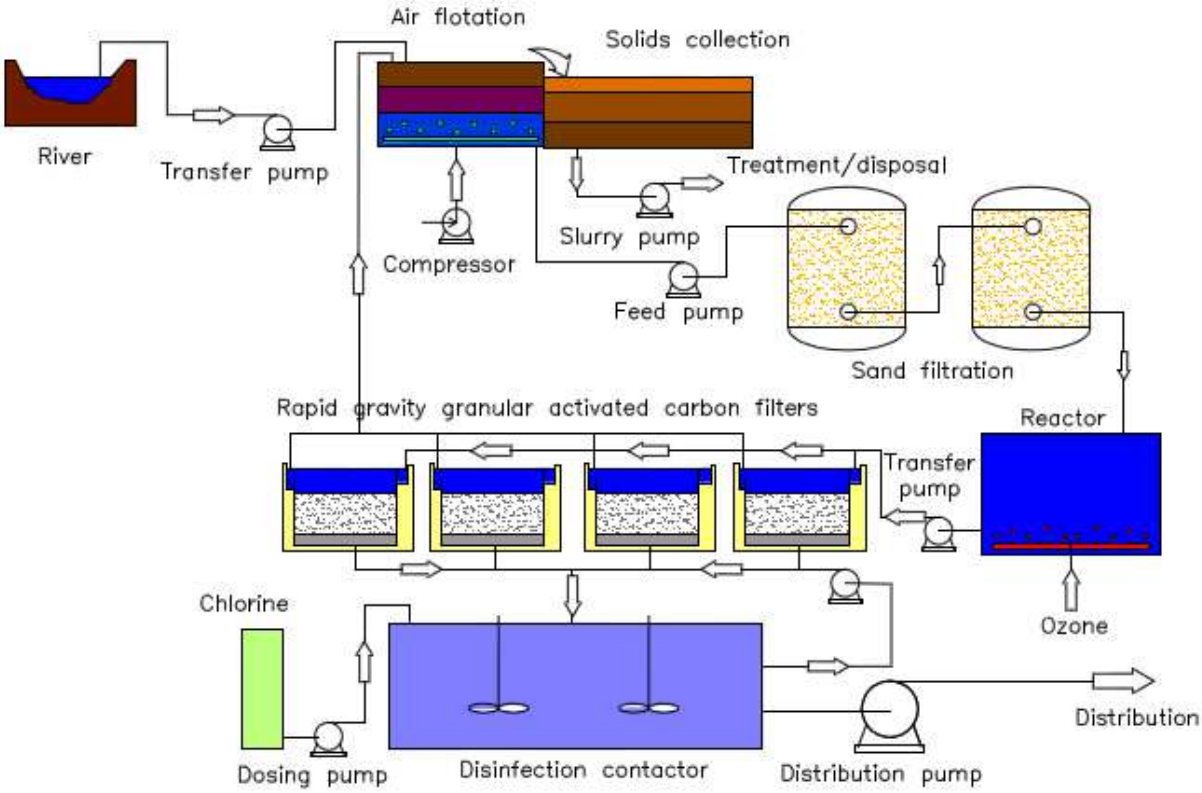


Fig. 3.3 Municipal water treatment plant scheme - City of Oulu [9]

Raw water is pumped from the river through water pretreatment into a flotation unit (4 flotation units), which is used for the removal of suspended solids such as algae and particular material. Dissolved air is injected under pressure into the basin through special nozzles. The result is a layer of suspended solids on the surface of the water, which is removed using a mechanical skimming technique [9].

After flotation purification process water is further pumped into sand filtration (eight sand filters are working), where is produced high quality water free from pathogens, taste and odor [9].

Disinfection is solved as combination of ozone and sodium hypochloride and ammoniumchloride. Ozone is injected into the water to provide a powerfull bacterial action and to break down the natural humic compounds [9].

Finally the water enters a rapid gravity filtration system, which is used to absorb the compounds resulting from the ozone treatment [9].

PHOTOS FROM PURIFICATION WATER TREATMENT PLAT OF HINTTA:

Fig. 3.4 Pump station (Qact.=672 l/s)

Fig. 3.5 Screens

Fig. 3.6 Flotation units

Fig. 3.7 Control room

3.2 WATER PURIFICATION PLANT MOSTIŠTĚ

Water purification plant Mostiště is the only water purification plant in Czech Republic with flotation technology. In the year 2005 was performed its reconstruction by reason of decline of raw water quality, bad technical conditions of the water treatment plant and problematical quality of clarified water. One part of a reconstruction was replacement lamella sedimentation tanks by flotation units [11].

Water treatment plant´s capacity is 220 l/s and to its served territory belong Velké Meziříčí, Velká Bíteš, Měřín, Třebíč and Žďár nad Sázavou [11].

Water treatment processes in Mostiště:

- Cascading tray aeration
- Coagulation with ferric sulphate
- Flocculation
- First separation process – flotation units (or original clarifiers with lamella separator)
- Sand filtration
- Disinfection with chlorine and chlorine dioxide (ClO_2) [11].

Raw water has been taken from the dam Mostiště, constructed on the river Oslava. Raw water is injected into cascading tray aerators. After aeration ferric sulphate is dosed as coagulant.

Suspension after coagulation continuous dissolved air flotation units. There are two units with capacity 110 l/s per one unit. In case of higher water amount can work in parallel to flotation units two units of original clarifiers with lamella separator.

Further is water pumped into sand filtration, where is produced high quality water free from pathogens, taste and odor.

Finally is water disinfected with chlorine and chlorine dioxide (ClO_2) and pH is adjusted with lime.

Drinking water is accumulated in retention tanks within volume about 900 m^3 [11].

3.2.1 WATER TREATMENT PLANT SCHEME

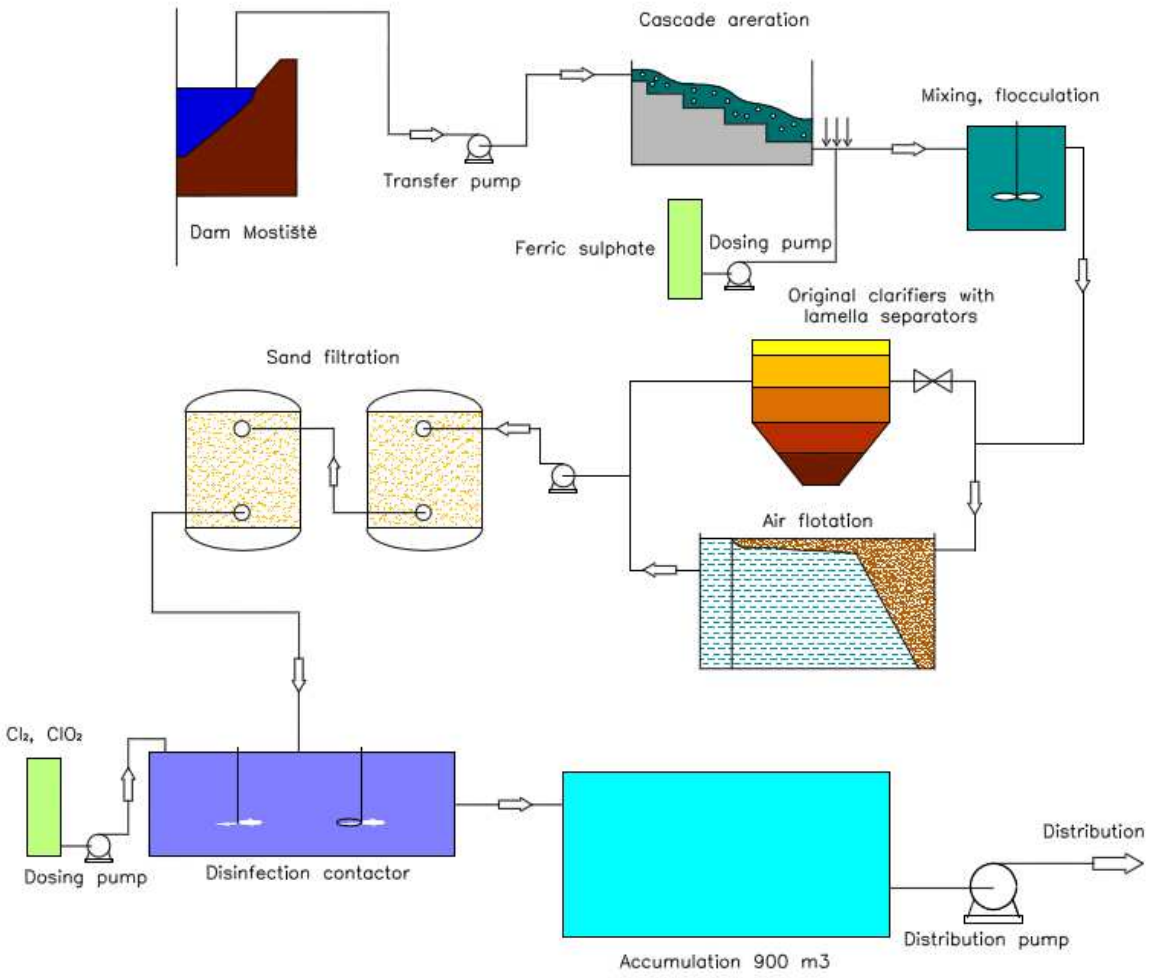


Fig. 3.8 Municipal water treatment plant scheme - Mostiště

PHOTOS FROM PURIFICATION WATER TREATMENT PLANT MOSTIŠTĚ:

Fig. 3.9 Flotation unit in water treatment plant Mostiště [10]

FFig. 3.10 Outlet from flotation unit [10]

4 PRACTICAL RESEARCH

4.1 RESEARCH OBJECTIVES

Goal of this research was to recognize dissolved air flotation efficiency by the help of turbidity and UV absorbance removal in different conditions. As different conditions are meant the efficiency for different baffle position, different detention time in separation zone and checking results with adding chemicals compared to results without adding chemicals.

At the beginning for introduction with laboratory water treatment process were described water treatment units-from aeration to disinfection. Of course description is focused on flotation tank.

The next very important part is calculation. Before start research was necessary to count values as detention time and hydraulic load for contact zone and the length of separation zone. (Chapter 4.3 Calculation)

After that was made model research in mentioned water treatment laboratory. All results were written into pre-prepared tables and then these values were evaluated into graphs. (Chapter 4.4 Results).

At the end were made comparison between individual parts and conclusion as well.

Note:

Turbidity is the cloudiness or haziness of a fluid caused by individual particles (suspended solids) that are generally invisible to the naked eye, similar to smoke in air. The measurement of turbidity is a key test of water quality [5]. Turbidity units are NTU.

UV Absorbance is the logarithm of the ratio of the intensities of the incident light ($\boldsymbol{I_o}$) and the transmitted light ($\boldsymbol{I}$). It is related according to the Beer-Lambert Law. The ordinate of the chromatogram represents the detector signal, which in general, is proportional to the analyte concentration in the cell. Since chromatographic systems permit the quantitative analysis of sample components representing many orders of magnitude - from ppm to percent concentrations - one may select, various amplification ranges so that the visual display of components (both small and large) [6]. UV Absorbance units are 1/m.

4.2 LABORATORY

Raw water was taken from the river Oulujoki, about 1 meter under water surface. Its pH was approximately 7,3 and had variable turbidity. Pressure of saturated air in retention tank was being adjusted on the value 4,5-5,0 bar.

Raw water in laboratory is accumulated in two accumulation tanks inside the laboratory. From them is raw water pumped into accumulation under the ceiling to provide gravitation process. Water treatment capacity in laboratory is about 6 l/min.

First part of the treatment process is pretreatment with aeration, dosing chemicals (coagulants and chemicals regulating pH) and due to followed mixing, flocs aggregations are created in two flocculation tanks. Pressured air is taken from the saturator next to aeration tank.

As first separation process is possible to choose between sedimentation and flotation by closing (opening) valves. In this master´s thesis for model research on the efficiency of turbidity and UV absorbance removal was chosen flotation unit.

From the first separation unit (in this case DAF) water is pumped into second separation process. It was used traditionally sand filtration, specifically slow sand filter.

At the end is water disinfected by UV disinfection. Then is clarified water accumulated into two small tanks to make laboratory tests of water quality.

Each tank is equipped with probes for continual measuring pH values and conductivity. Some of them have probes for measuring turbidity. Everything is displayed on the control panel in laboratory.

4.2.1 WATER TREATMENT SCHEME

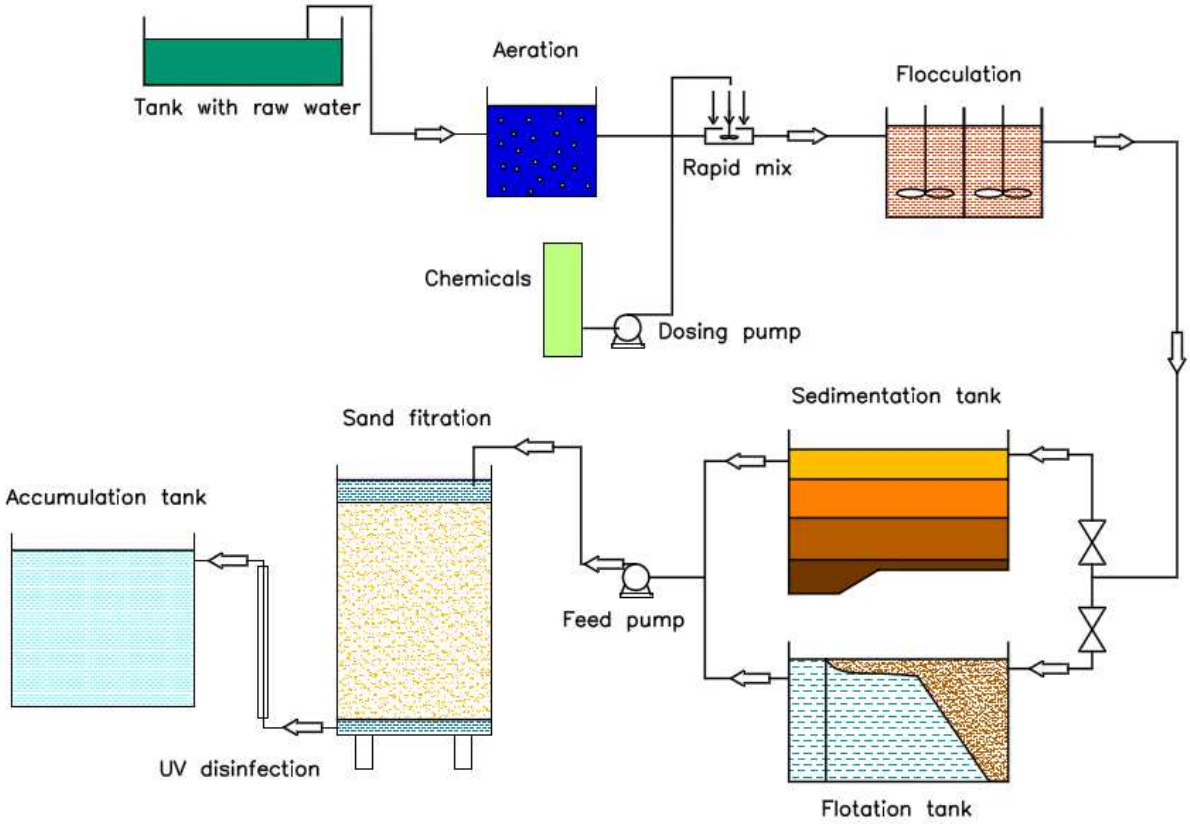


Fig. 4.1 Water treatment plant scheme - laboratory

Water treatment processes in laboratory are these:

- Aeration
- Coagulation and flocculation
- Sedimentation or flotation
- Sand filtration
- UV disinfection
- Accumulation.

4.2.2 WATER TREATMENT PROCESSES

WHOLE LABORATORY

Fig. 4.2 Laboratory water treatment plant

Fig. 4.3 Laboratory water treatment plant-back view

ACCUMULATION TANKS FOR RAW WATER

Fig. 4.4 Tanks with raw water

Fig. 4.5 Tank with raw water-under ceiling

AERATION

Fig. 4.6 Aeration tank and saturator

Aeration is a process used in water treatment to remove dissolved gases such as carbon dioxide, hydrogen sulfide, other taste- and odor-causing compounds and volatile organic compounds (VOC). Aeration is also used to add oxygen from air into water, to oxidize iron and manganese and to prevent formation of reducing environments that exacerbate taste and odor problems.

There are available several methods to oxygenate water:

- Spray nozzles – the most common application is the fountain-type aerator. They are used in source water reservoirs to control taste and odor problems, prevent anaerobic decay of natural organic matter and prevent solubilization of iron and manganese
- Cascading tray aerators – use multistage waterfalls to control taste and odor problems and precipitate soluble iron and manganese.
- Diffused aeration – is not often used in the water treatment.
- Packed tower stripping – is widely used because of regulation VOCs in drinking water [1].

FLOCCULATION

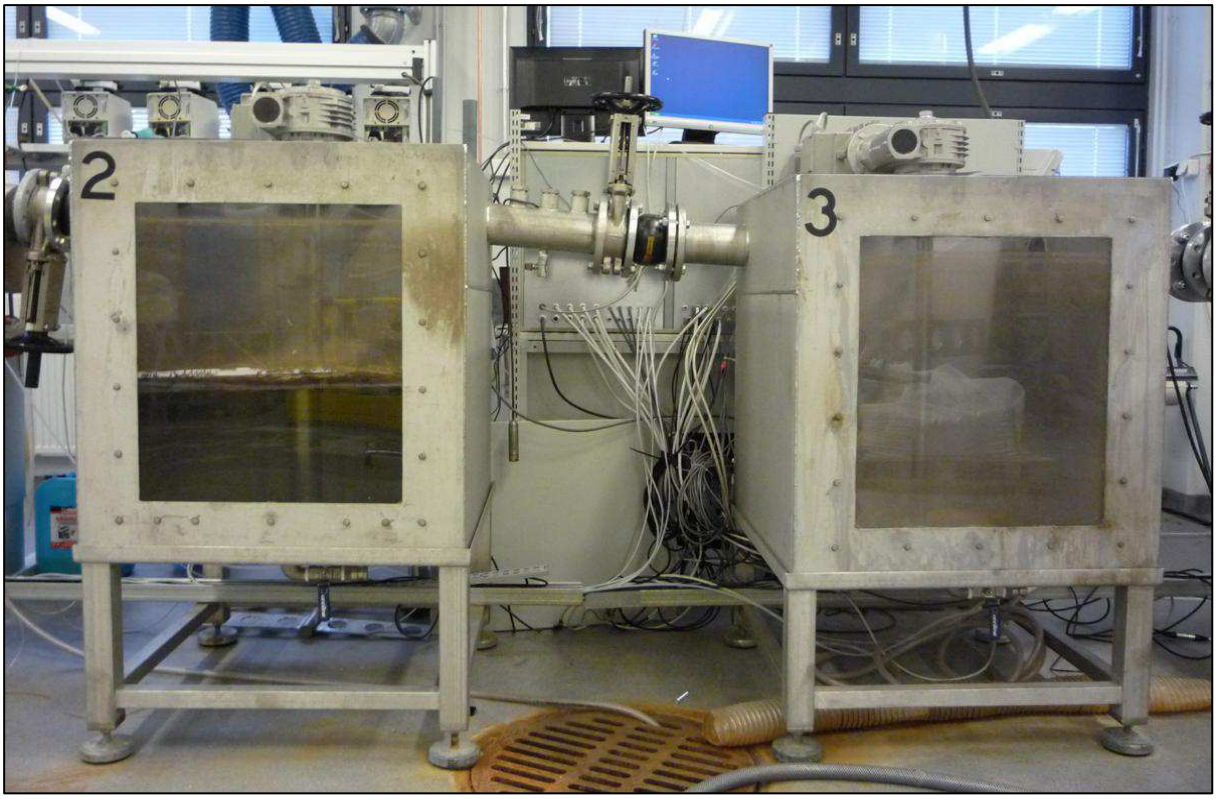


Fig. 4.7 Flocculation

Coagulation processes are used in water treatment plant to promote aggregation of small particles into larger particles that they are more easily removed by sedimentation or filtration. Coagulation processes are based on the destabilization of stable particulate suspensions in water.

Particulate suspensions are commonly removed with coagulation processes include clay- and silt-based turbidity, natural organic matter and others, such as microbial contaminants, toxic metals, synthetic organic chemicals, iron and manganese.

Coagulation process consists of three sequential steps:

- Coagulant formation
- Particle destabilization
- Particle aggregation.

Coagulant formation and particle destabilization are promoted in rapid-mixing stage with adding chemicals. Particle aggregation is then promoted in a flocculation stage [1].

SEDIMENTATION

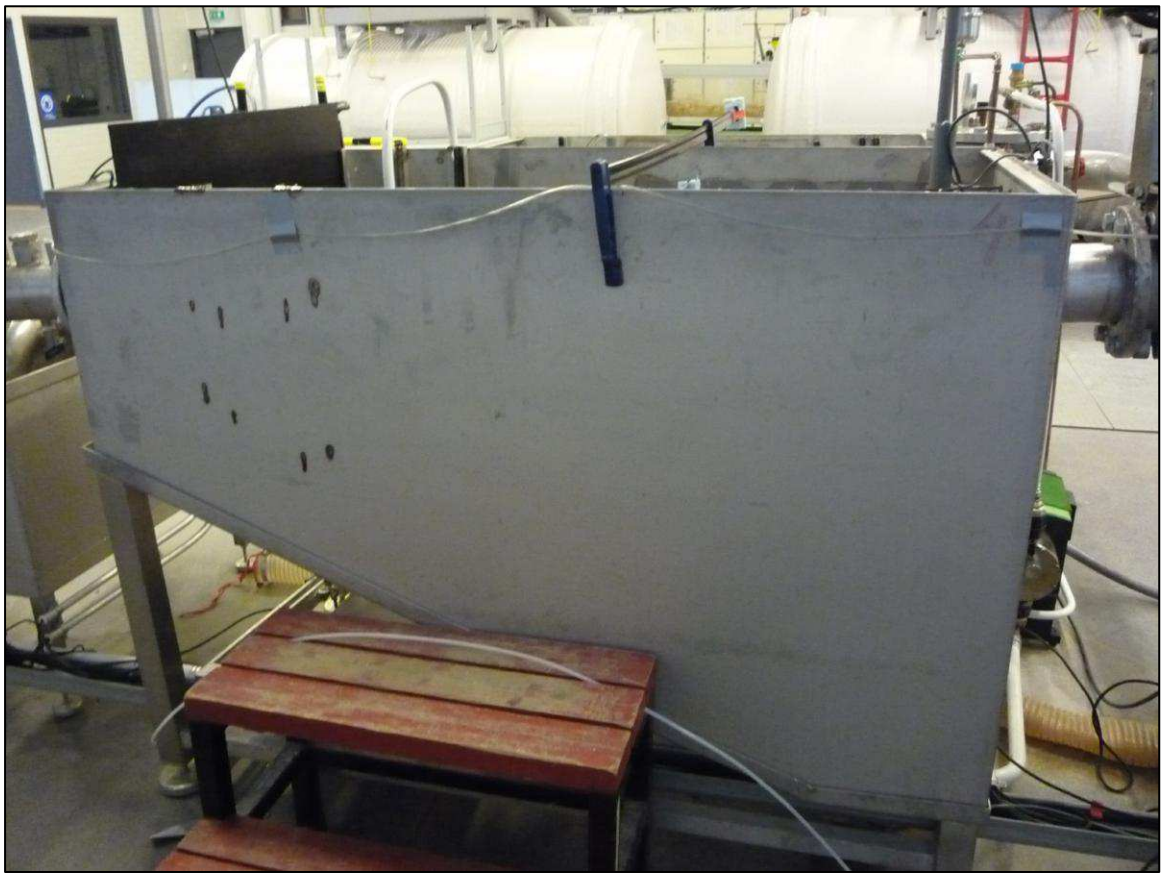


Fig. 4.8 Sedimentation tank

Sedimentation and flotation are solid-liquid gravity separation processes. Sedimentation processes promote gravity settling of solid particles to the bottom of the water column where accumulated solids are removed.

Sedimentation is generally used in combination with coagulation and flocculation to remove floc particles and improve subsequent filtration efficiency. Sedimentation is particularly necessary for high-turbidity and highly colored waters.

Sedimentation is sometimes used as the head of a water treatment plant in the form of a pre-sedimentation basin to allow gravity settling of denser solids. This method is often used when surface water has a high silt or turbidity content.

Many types of sedimentation tanks are available: A horizontal-flow rectangular tank, A horizontal multistory tanks, circular radial-flow tanks, inclined settlers (plate and tube), cross-flow settling, etc. [1]

FLOTATION

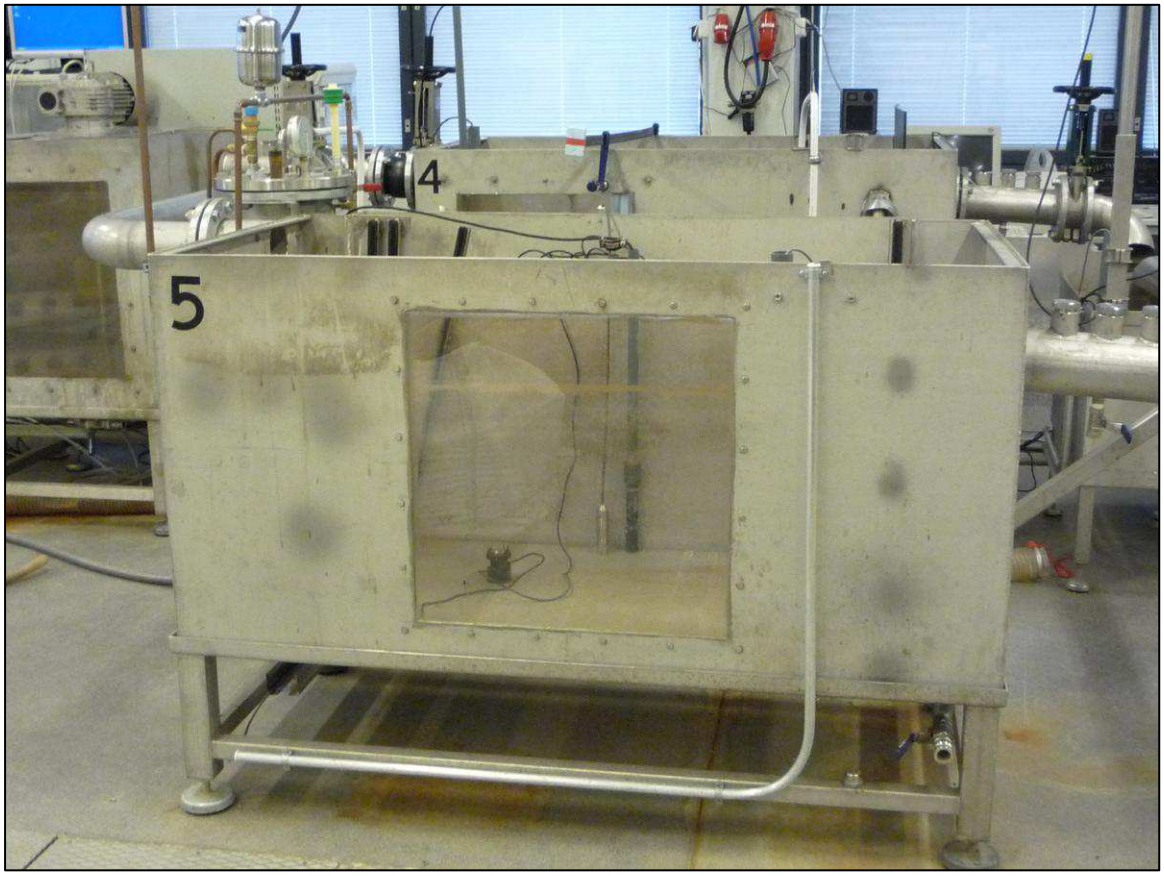


Fig. 4.9 Flotation tank

Flotation processes introduce gas bubbles into the water that attach to solid particles and create bubble-solid agglomerates. Then they float to the top of the water column where accumulated solids are removed.

Flotation is gaining acceptance in Europe as an alternative to sedimentation for algal-laden, low turbidity, low alkalinity, colored waters that produce lower-density floc less amenable to sedimentation [1].

On flotation is closely focused in Chapter 2 – THEORY.

SAND FILTRATION

Fig. 4.10 Sand filtration

Filtration is the process relied on most water treatment facilities for the removal of suspended particulate matter. Common particulates removed in water treatment filtration are clay and silt, colloidal and precipitated natural organic matter, metal salt precipitates from coagulation, lime softening precipitates, iron and manganese precipitates and microorganisms.

The most common type of filter used in potable water treatment are granular media filters. Granular media filters can be obtained in vessels open or closed to the atmosphere with gravity flow or pressurized passage through the filter media. It appears from this that we have these four main types of filters: Rapid (gravity) sand filters, rapid (pressure) sand bed filters, upflow sand filters and slow sand filters [1].

UV DISINFECTION

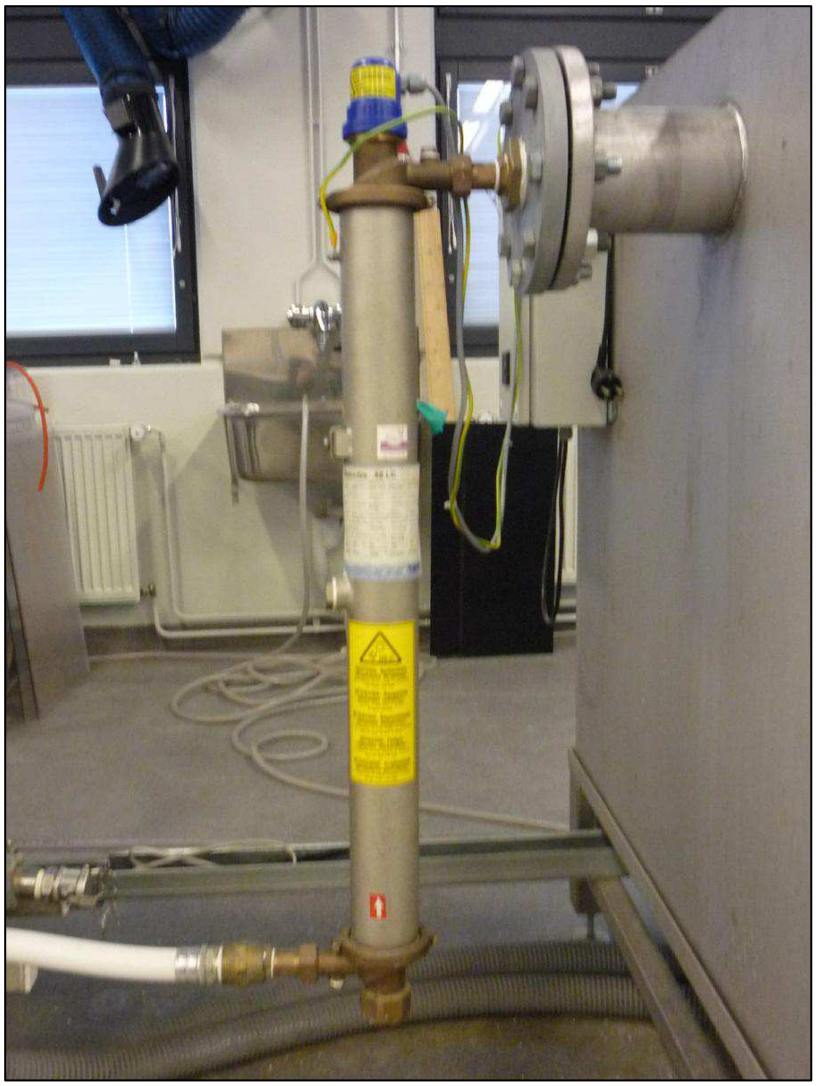


Fig. 4.11 UV disinfection

Disinfection is provided in water treatment to assure the production of a microbiologically safe finished water quality. Disinfectants include free and combined chlorine, chlorine dioxide, ozone, ultraviolet (UV) irradiation, and other disinfectants such as potassium permanganate, heat or extremes in pH.

UV radiation is a good biocide but like ozone provides no persistent residual for distribution protection. UV disinfection is more practical for smaller-capacity plants. UV radiation requires a secondary disinfectant to provide residual for distribution protection [1].

ACCUMULATION TANKS FOR CLARIFIED WATER

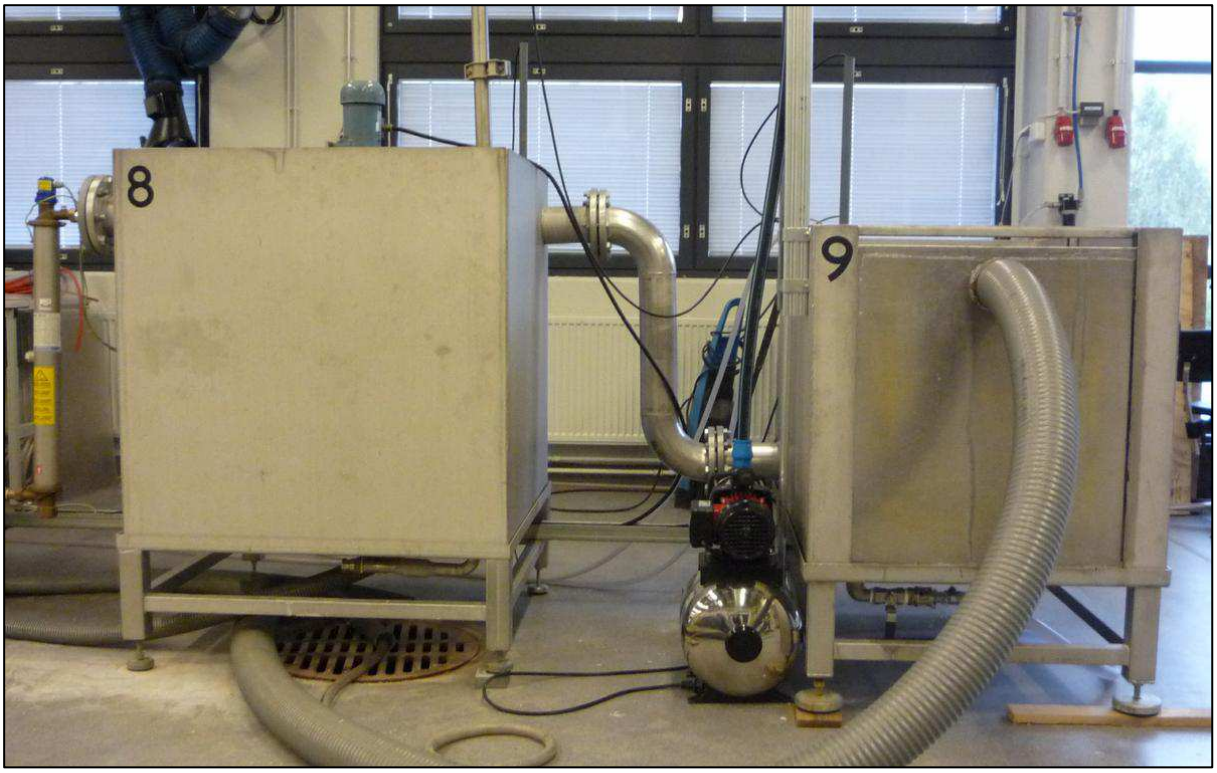


Fig. 4.12 Accumulation tanks for clarified water

DOSING PUMPS

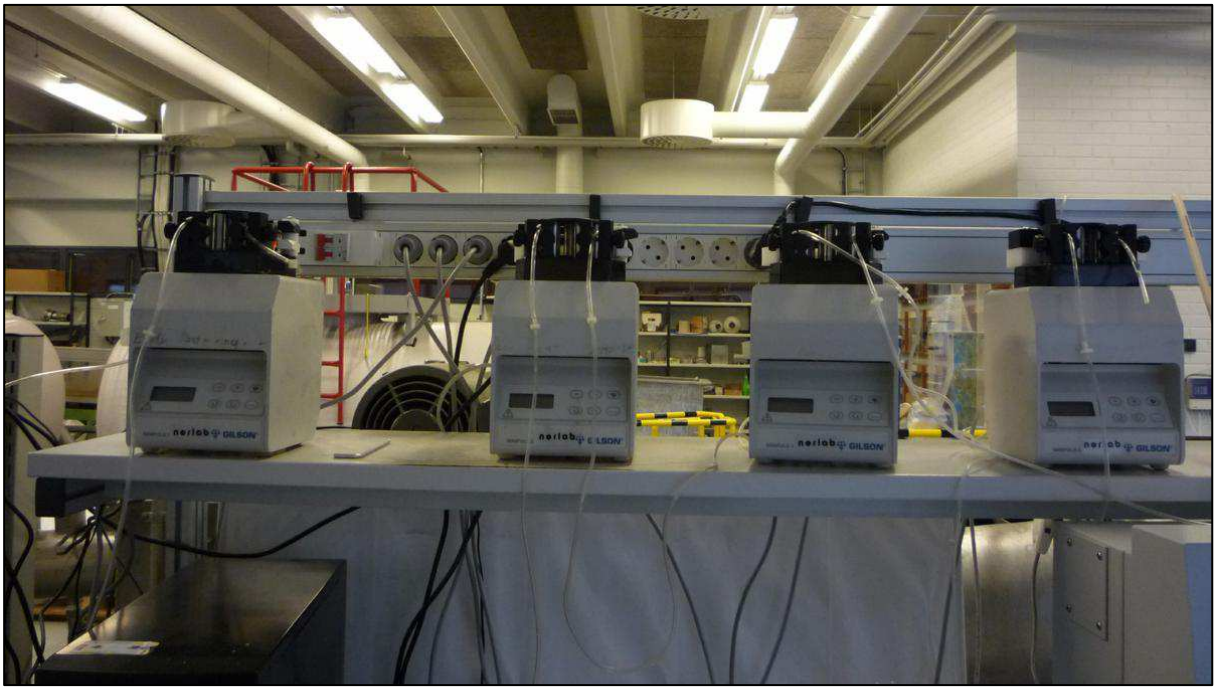


Fig. 4.13 Dosing pumps for chemicals

CONTROL PANELS

Fig. 4.14 Control panel with conductivity and pH values

Fig. 4.15 Control panel with turbidity values

4.2.3 FLOTATION TANK SCHEME

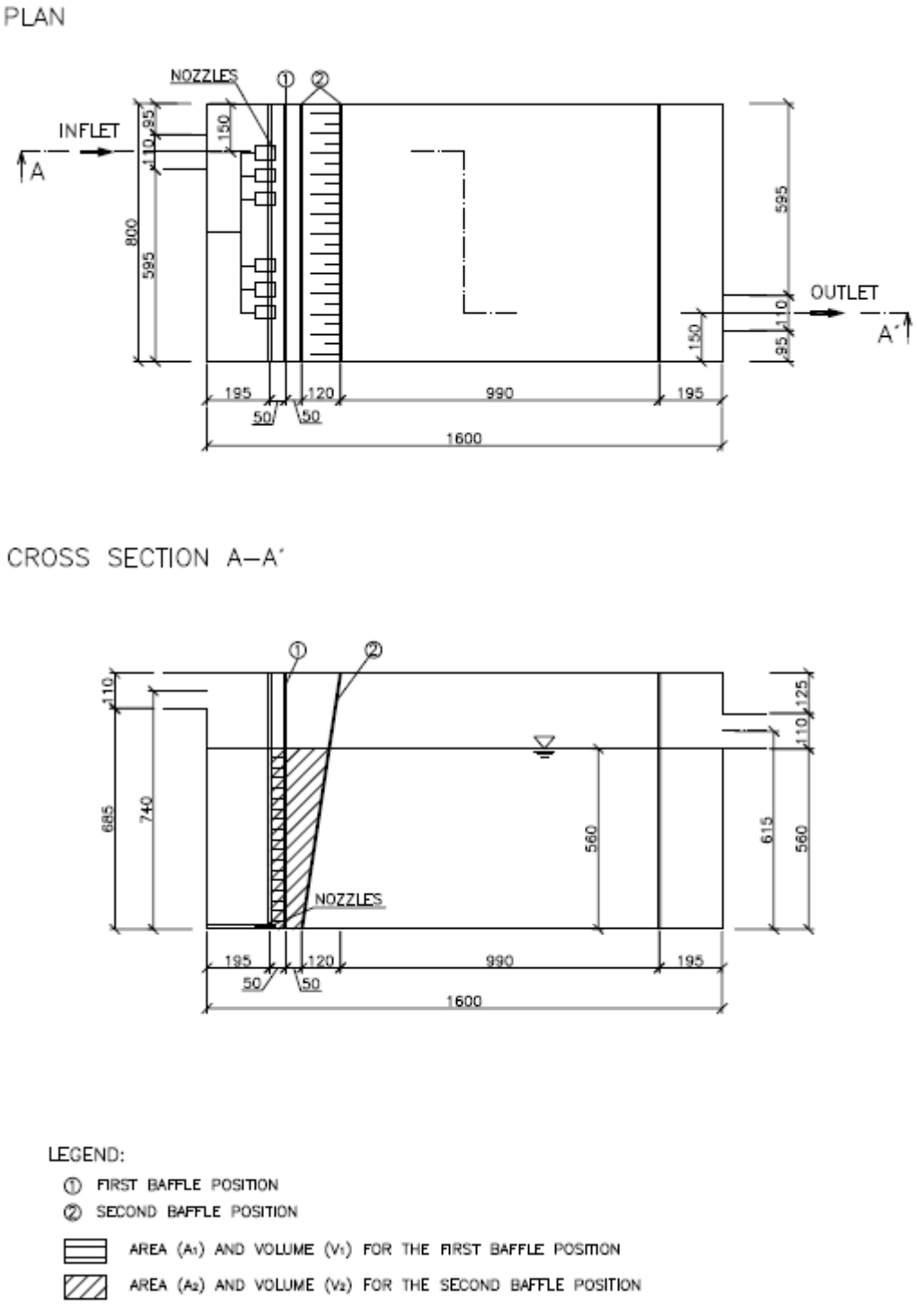


Fig. 4.16 Flotation tank scheme

3D model of flotation tank

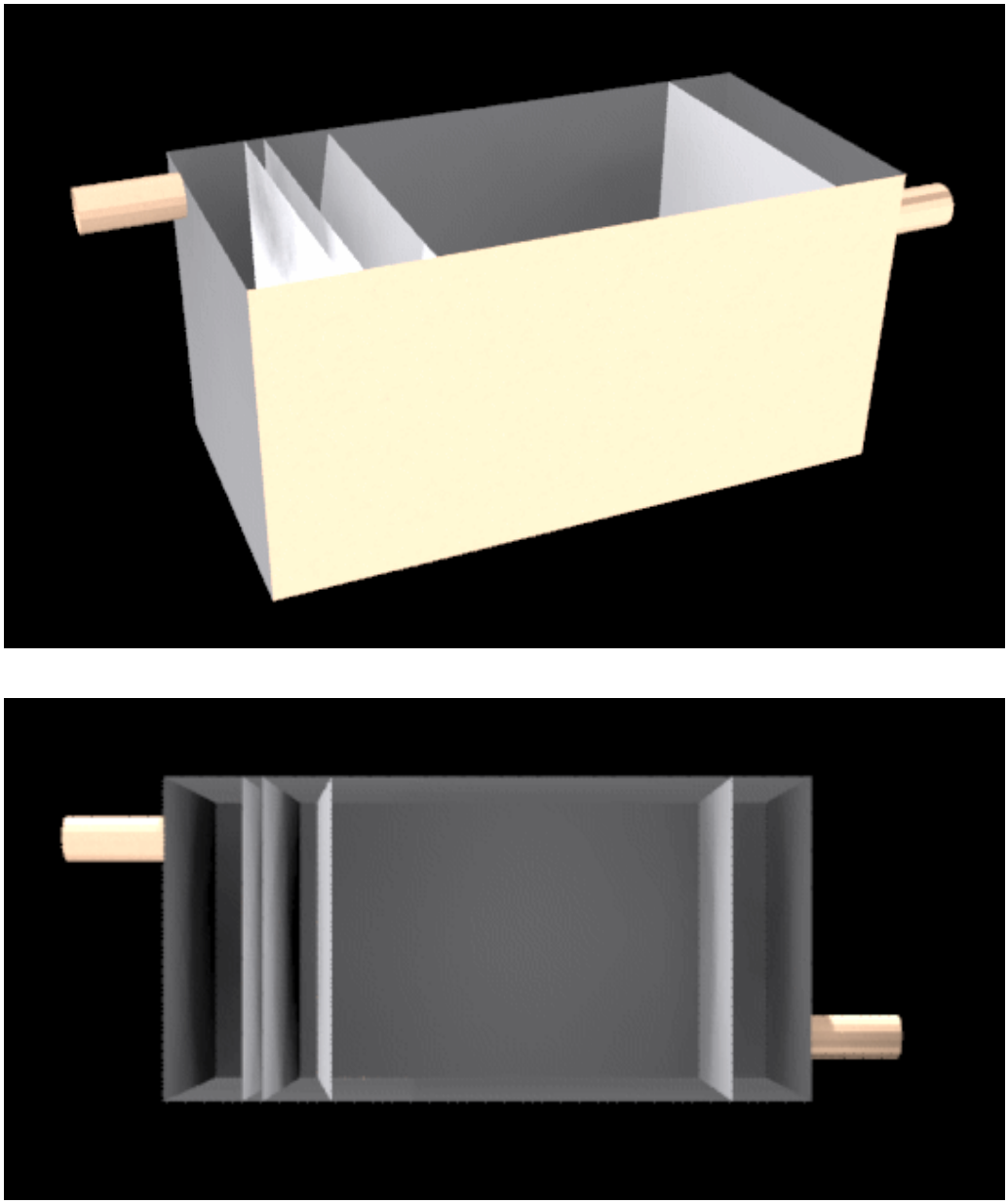


Fig. 4.17 Flotation tank – 3D MODEL

FLOTATION TANK DIMENSIONS:

- length: l=1,6 m
- depth: b=0,8 m
- height: h_1=0,8 m
- head of water: h_2=0,56 m

FLOW:

- Q=6,24 l/min = 0,104 l/s

Pictures from laboratory

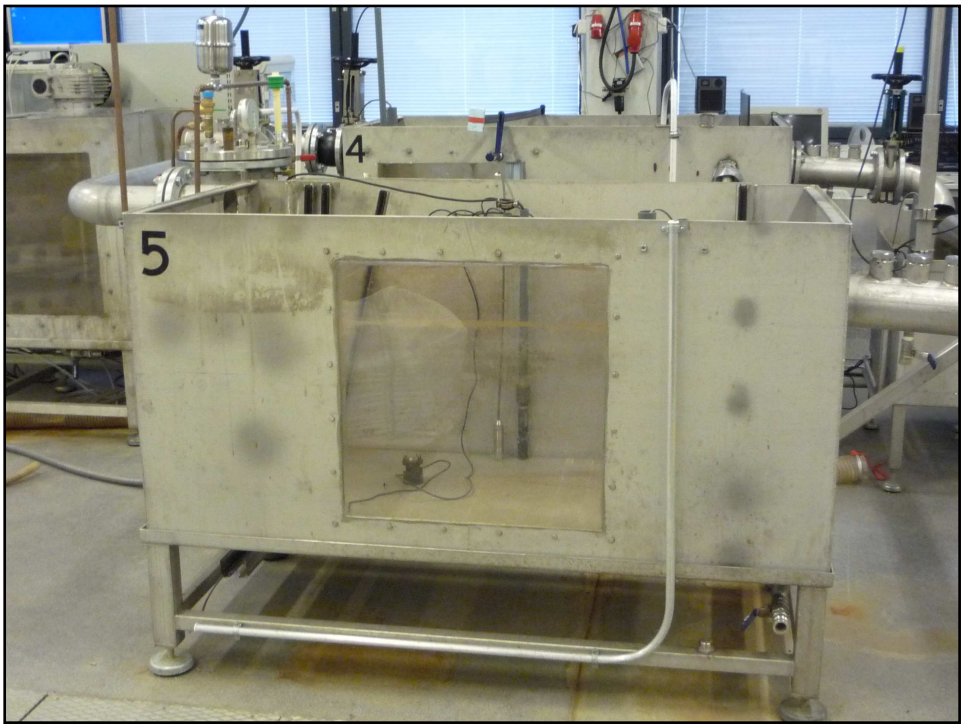


Fig. 4.18 Flotation tank - photo 1

Fig. 4.19 Flotation tank - photo 2

4.3 CALCULATIONS

4.3.1 DETENTION TIME AND HYDRAULIC LOAD FOR CONTACT ZONE

As the first step was need to make some calculations of flotation tank. In follow Table 4.1 are calculated detention times and hydraulic loads in contact zone for both baffle positions.

Values:

Q_{in} = 6,24 l/min = 0,3744 m^3/h ... inflow

A_1 = 0,04 m^2 .... area for the first baffle position

V_1 = 0,022 m^3 .... volume for the first baffle position

A_2 = 0,08 m^2 ... area for the second baffle position

V_2 = 0,072 m^3 ... volume for the second baffle position

Equations:

$$Q_{out} = Q_{in} + Q_{air} \qquad (4.1)$$

$$v = Q/A \qquad (4.2)$$

$$T = V/Q \qquad (4.3)$$

By the help of equations 4.1; 4.2 and 4.3 was filled next table, where is counted detention time and hydraulic load of contact zone for different amount of air flow (Q_{air}) – 10, 15, 20 % of Q_{in}.

Tab. 4.1 Hydraulic load and detention time in contact zone for different values of Qair

Q_{air}[%]	Q_{air}[m^3/h]	Q_{out}[m^3/h]	v_1 [m/h]	T_1 [h]	v_2 [m/h]	T_2 [h]
10 %	0,03744	0,412	10,30	0,053	5,148	0,176
15 %	0,05616	0,431	10,76	0,051	5,382	0,168
20 %	0,07488	0,450	11,23	0,049	5,616	0,161

Where:

Q_{in} ... inflow [m^3/s]

Q_{air} ... air flow [m^3/s]

Q_{out} ... outflow [m^3/s]

v_1 ... hydraulic load in contact zone for the first baffle position [m/h]

T_1 ... detention time in contact zone for the first baffle position [h]

v_2 ... hydraulic load in contact zone for the second baffle position [m/h]

T_2 ... detention time in contact zone for the second baffle position [h]

Units transfer:

T_1 (10% Q_{air}) = 0,053 h = 3 min and 12sec

T_1 (15% Q_{air}) = 0,051 h = 3 min and 4 sec

T_1 (20% Q_{air}) = 0,049 h = 2 min and 56 sec

T_2 (10% Q_{air}) = 0,176 h = 10 min and 32 sec

T_2 (15% Q_{air}) = 0,168 h = 10 min and 5 sec

T_2 (20% Q_{air}) = 0,161 h = 9 min and 39sec

4.3.2 LENGTH OF SEPARATION ZONE

Secondly were being counted different lengths of separation zone in depends on detention times. Chosen detention times are 5; 10; and 15 minutes.

Values:

Q_{out} = 0,431 m^3/h ... average outflow

d = 0,6 m ... water depth

b = 0,8 m ... flotation tank width

Equations:

$$V = l \cdot d \cdot b \quad \Rightarrow \quad l = V/(d \cdot b) \qquad (2.4)$$

$$T = V/Q \quad \Rightarrow \quad V = T \cdot Q \qquad (2.5)$$

Note: Due to very small differences between amounts of Q_{air}, was chosen only one Q_{out} value (average of Q_{out} values) and was being counted just with it.

Table:

Tab. 4.2 Separation zone lengths depending on different detention times

T [min]	T [h]	V [m^3]	l [m]	l [cm]
5	0,0833	0,0359	0,075	7,5
10	0,1667	0,0718	0,150	15,0
15	0,2500	0,1076	0,224	22,4

From this table results that:

l_{5min} = 7,5 cm ... for detention time 5 min is the length 7,5 cm (meant only for separation zone)

l_{10min} = 15 cm ... for detention time 15 min is the length 15 cm (meant only for separation zone)

l_{15min} = 22,4 cm ... for detention time 22,4 min is the length 22,4 cm (meant only for sep.zone)

4.4 RESULTS

Results are divided into several parts. Below is introduced some small view of results parts to help understand the follow tables. The firs main two parts are results for cases with and without adding chemicals, then is each of that parts divided into another two parts, namely for the first baffle position and for the second baffle position.

Results view:

1. Without adding chemicals

1.1. For the 1st baffle position

1.1.1. With Q_{air} = 10 % of Q_{in}

1.1.1.1. For detention time in separation zone T_s = 5 min

1.1.1.2. For detention time in separation zone T_s = 10 min

1.1.1.3. For detention time in separation zone T_s = 15 min

1.1.2. With Q_{air} = 15% of Q_{in}

1.1.2.1. For detention time in separation zone T_s = 5 min

1.1.2.2. For detention time in separation zone T_s = 10 min

1.1.2.3. For detention time in separation zone T_s = 15 min

1.1.3. With Q_{air} = 20% of Q_{in}

1.1.3.1. For detention time in separation zone T_s = 5 min

1.1.3.2. For detention time in separation zone T_s = 10 min

1.1.3.3. For detention time in separation zone T_s = 15 min

1.2. For the 2nd baffle position

1.2.1. With Q_{air} = 10 % of Q_{in}

1.2.1.1. For detention time in separation zone T_s = 5 min

1.2.1.2. For detention time in separation zone T_s = 10 min

1.2.1.3. For detention time in separation zone T_s = 15 min

1.2.2. With Q_{air} = 15% of Q_{in}

1.2.2.1. For detention time in separation zone T_s = 5 min

1.2.2.2. For detention time in separation zone T_s = 10 min

1.2.2.3. For detention time in separation zone T_s = 15 min

1.2.3. With Q_{air} = 20% of Q_{in}

1.2.3.1. For detention time in separation zone T_s = 5 min

1.2.3.2. For detention time in separation zone T_s = 10 min

1.2.3.3. For detention time in separation zone T_s = 15 min

2. With adding chemicals

2.1. <u>For the 1st baffle position</u>

2.1.1. With Q_{air} = 10 % of Q_{in}

2.1.1.1. For detention time in separation zone T_s = 5 min

2.1.1.2. For detention time in separation zone T_s = 10 min

2.1.1.3. For detention time in separation zone T_s = 15 min

2.1.2. With Q_{air} = 15% of Q_{in}

2.1.2.1. For detention time in separation zone T_s = 5 min

2.1.2.2. For detention time in separation zone T_s = 10 min

2.1.2.3. For detention time in separation zone T_s = 15 min

2.1.3. With Q_{air} = 20% of Q_{in}

2.1.3.1. For detention time in separation zone T_s = 5 min

2.1.3.2. For detention time in separation zone T_s = 10 min

2.1.3.3. For detention time in separation zone T_s = 15 min

2.2. <u>For the 2nd baffle position</u>

2.2.1. With Q_{air} = 10 % of Q_{in}

2.2.1.1. For detention time in separation zone T_s = 5 min

2.2.1.2. For detention time in separation zone T_s = 10 min

2.2.1.3. For detention time in separation zone T_s = 15 min

2.2.2. With Q_{air} = 15% of Q_{in}

2.2.2.1. For detention time in separation zone T_s = 5 min

2.2.2.2. For detention time in separation zone T_s = 10 min

2.2.2.3. For detention time in separation zone T_s = 15 min

2.2.3. With Q_{air} = 20% of Q_{in}

2.2.3.1. For detention time in separation zone T_s = 5 min

2.2.3.2. For detention time in separation zone T_s = 10 min

2.2.3.3. For detention time in separation zone T_s = 15 min

4.4.1 TABLE FOR FILLING

For lucidity is shown follow table (Tab.4.3), where had been written values from measuring. In total were filled four tables namely for:

- Case without adding chemicals – 1. baffle position (first table)
  - 2. baffle position (second table)
- Case with adding chemicals – 1. baffle position (fourth table)
  - 2. baffle position (fifth table)

Tab. 4.3 Table for filling

	Detention time in contact zone	$l_{sep.z.}$ [cm]	Detention time in sep. zone	Total detention time	pH [-]		Turbidity [NTU]			UV absorbance [1/M]		
					1*	2*	1*	2*	%	1*	2*	1*-2*
Q_{air}[10%]	3min 12s (I) 10min 32s (II)	-	0									
		7,5	5min									
		15,0	10min									
		22,4	15min									
Q_{air}[15%]	3min 4s (I) 10min 5s (II)	-	0									
		7,5	5min									
		15,0	10min									
		22,4	15min									
Q_{air}[20%]	2min 56s (I) 9min 39s (II)	-	0									
		7,5	5min									
		15,0	10min									
		22,4	15min									

1* ...raw water
2* ... water after flotation
% ... percentage of removal

Each table was divided into three parts according to amount of dissolved air (Qair), namely for Qair=10% (1) of Qin, Qair=15% (2) of Qin and Qair=20% of Qin (3).

In first column, called “Detention time in contact zone”, were indeed counted detention times in contact zone (see chapter 4.3.1). These values are different for the first baffle position – in the table 4.3, noted “(I)” and for the second baffle position, noted “(II)”.

Second column, named “$l_{sep.z.}$”, shows values for separation zone length, where were counted from given values (for 5min,10min and 15min) in third column, entitled “Detention time in separation zone” (see chapter 4.3.2). Total detention time in fourth column is just summary of Detention time in contact zone and Detention time in separation zone.

Into follow columns had been written values from measuring concretely pH values, Turbidity and UV absorbance always for raw water, or water before flotation process (1*) and for water after purification with flotation process (2*). Finally was counted percentage of turbidity and UV absorbance removal.

4.4.2 MEASURING WITHOUT ADDING CHEMICALS

Results for the first baffle position without adding chemicals

The follow table (4.4) shows us results of turbidity and UV absorbance removal for the *first baffle position*.

Tab. 4.4 Results for the first baffle position without adding chemicals

Results for the 1st baffle position (A_1 =0,04m^2 a V_1 =0,024m^3)

	Detention time in contact zone	$l_{sep.z.}$ [cm]	Detention time in sep. zone	Total detention time	pH [-]		Turbidity [NTU]			UV absorbance [1/M]		
					1*	2*	1*	2*	%	1*	2*	1*-2*
Q_{air}-[10%]	3min 12s	-	0	0	*7,43*	*7,06*	*5,57*	*5,17*	*7,18*	*3,98*	*4,16*	*-0,18*
		7,5	5min	8min 12s	*7,43*	*7,15*	*5,33*	*4,90*	*8,07*	*3,97*	*4,16*	*-0,19*
		15,0	10min	13min 12s	*7,44*	*7,23*	*6,93*	*5,60*	*19,19*	*3,97*	*4,16*	*-0,19*
		22,4	15min	18min 12s	*7,45*	*7,09*	*7,89*	*6,32*	*19,90*	*3,56*	*3,56*	*0,00*
Q_{air}-[15%]	3min 4s	-	0	0	*7,41*	*6,83*	*5,69*	*5,24*	*7,91*	*3,45*	*3,40*	*0,05*
		7,5	5min	8min 4s	*7,41*	*6,99*	*5,44*	*5,14*	*5,51*	*3,49*	*3,35*	*0,14*
		15,0	10min	13min 4s	*7,40*	*6,97*	*6,54*	*5,73*	*12,39*	*-0,30*	*0,00*	*-0,30*
		22,4	15min	18min 4s	*7,41*	*7,01*	*7,62*	*6,21*	*18,50*	*-0,70*	*-0,60*	*-0,10*
Q_{air}-[20%]	2min 56s	-	0	0	*7,40*	*6,92*	*5,63*	*5,21*	*7,46*	*-0,90*	*-0,80*	*-0,10*
		7,5	5min	7min 56s	*7,40*	*6,89*	*5,44*	*5,16*	*5,15*	*-0,70*	*-0,80*	*0,10*
		15,0	10min	12min 56s	*7,41*	*6,98*	*9,60*	*6,80*	*29,17*	*-0,10*	*0,00*	*-0,10*
		22,4	**15min**	**17min 56s**	***7,42***	***6,93***	***13,00***	***8,37***	***35,62***	*-0,20*	*-0,10*	*-0,10*

1* ...raw water
2* ... water after flotation
% ... percentage of removal

pH. pH values are nearly the same for all cases. It´s value is vary between 6,83 – 7,45.

Turbidity. From the column „% of turbidity removal“ is seen, that the highest efficiency (35,62%) was obtained in the last possibility, means for Q_{air} = 20% of Q_{in} and for the separation zone length $l_{sep.z}$ = 22,4 cm. The results comparison is better to see in the chart (3.1) below.

UV absorbance. Without using chemical was nearly impossible to decrease UV absorbance by the help of flotation. The most values of „UV absorbance removal“ are negative. That means, raw water has less amount of UV absorbance than water after flotation. The highest

reached value was 0,14 1/M of UV absorbance removal (for Q_{air} = 15% of Q_{in} and for $l_{sep.z.}$ = 7,5 cm).

The following chart (Fig. 4.20) represents effect of detention time on turbidity removal for flotation. There is also comparison of different air flow (Q_{air}) for the first baffle position.

Chart: Effect of detention time on turbidity removal

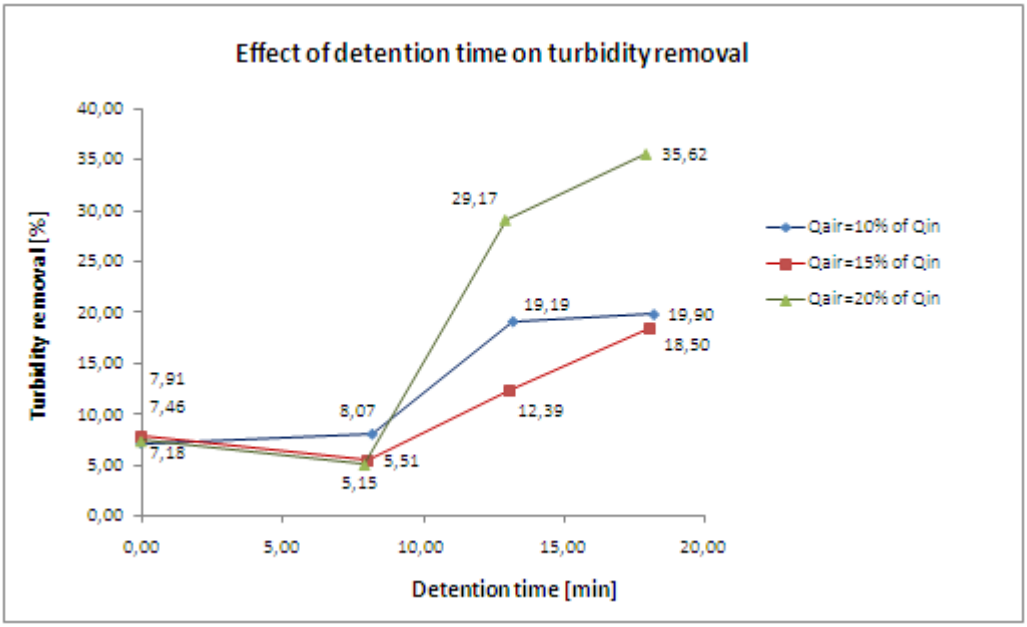


Fig. 4.20 Comparison of different air flow (Qair) for the first baffle position without adding chemicals

On the axis „X“, called Detention time, are plotted detention time values in minutes, the axis „Y“ represents Turbidity removal values in % - it means how many percentage of turbidity was removed after fixed time. The blue line illustrates values for Q_{air} = 10% of Q_{in}, the red line is for Q_{air} = 15% of Q_{in} and the green one is for Q_{air} = 20% of Q_{in}. In the same way were made next charts below.

Results for the second baffle position without adding chemicals

The follow table (4.5) contains results of turbidity and UV absorbance removal for the *second baffle position*. The second baffle position has bigger area and volume of contact zone.

In this case is measuring principle the same as in case of the first baffle position. With increasing area and volume also increases detention time in contact zone.

Tab. 4.5 Results for the second baffle position without adding chemicals

Results for the 2nd baffle position (A_2=0,08m^2 a V_2=0,077m^3)

	Detention time in contact zone	$l_{sep.z.}$ [cm]	Detention time in sep. zone	Total detention time	pH [-]		Turbidity [NTU]			UV absorbance [1/M]		
					1*	2*	1*	2*	%	1*	2*	1*-2*
Q_{air}[10%]	10min 32s	-	0	0	7,44	7,95	4,20	4,02	4,29	-0,40	-0,20	-0,20
		7,5	**5min**	**15min 32s**	***7,45***	***7,84***	***7,88***	***4,91***	***37,69***	-0,30	-0,10	-0,20
		15,0	10min	20min 32s	7,51	7,59	7,99	5,56	30,41	-0,30	-0,10	-0,20
		22,4	15min	25min 32s	7,59	7,48	9,66	6,17	36,13	-1,10	-0,30	-0,80
Q_{air}[15%]	10min 5s	-	0	0	7,65	7,17	6,00	5,33	11,17	-1,40	-1,40	0,00
		7,5	5min	15min 5s	7,62	7,03	5,95	4,96	16,64	0,70	0,65	0,05
		15,0	10min	20min 5s	7,56	7,37	5,01	5,03	-0,40	-1,50	-0,20	-1,30
		22,4	15min	25min 5s	7,59	7,51	4,46	4,98	-11,66	-1,40	-1,00	-0,40
Q_{air}[20%]	9min 39s	-	0	0	7,59	7,57	3,19	2,86	10,34	-0,40	0,01	-0,41
		7,5	5min	14min 39s	7,59	7,62	3,03	3,65	-20,46	-0,40	0,05	-0,45
		15,0	10min	19min 39s	7,61	7,50	3,24	3,39	-4,63	-0,20	-0,20	0,00
		22,4	15min	24min 39s	7,64	7,20	3,12	3,32	-6,41	-0,20	-0,30	***0,10***

1* ...raw water
2* ...after flotation
% ... percentage of removal

pH. pH values are nearly the same for all cases as in case of the first baffle position. It´s value is vary between 7,03 – 7,95.

Turbidity. From the column „% of turbidity removal" is seen, that the best results are for Q_{air} = 10% of Q_{in} and for the separation zone length $l_{sep.z}$ = 7,5 cm, the best efficiency is also 37,69 % of turbidity removal. The results comparison is better to see in chart (3.2) below.

UV absorbance. Of the second baffle position is true the same as of the first one - that without using chemicals was nearly impossible to decrease UV absorbance by the help of flotation. The highest value for this case is 0,10 1/M of UV absorbance removal (for Q_{air} = 20% of Q_{in} and for $l_{sep.z.}$ = 22,4 cm).

In following chart (Fig. 4.21) are demonstrated courses of the functions of effect for different Q_{air} depending on detention time.

Chart: Effect of detention time on turbidity removal

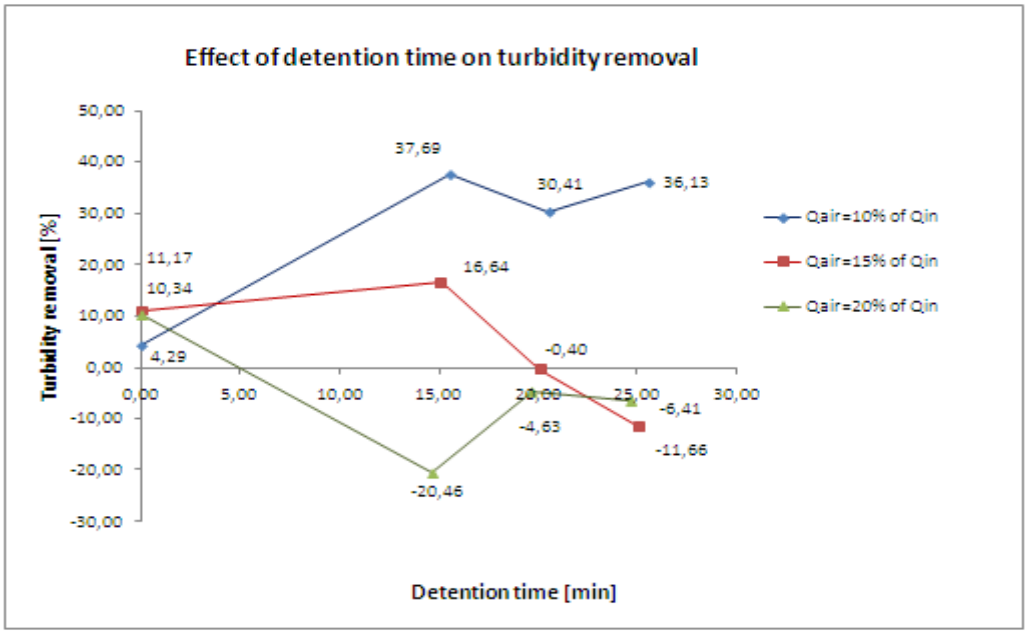


Fig. 4.21 Comparison of different air flow (Qair) for the second baffle position without adding chemicals

Effectivity comparison first baffle position with second one

The follow charts (Fig. 4.22; 4.23; 4.24) represent *effect of detention time on turbidity removal* for flotation process. There are illustrated comparisons of effect between first and second baffle position for the same Q_{air} *without adding chemicals*.

- For Q_{air} = 10% of Q_{in}

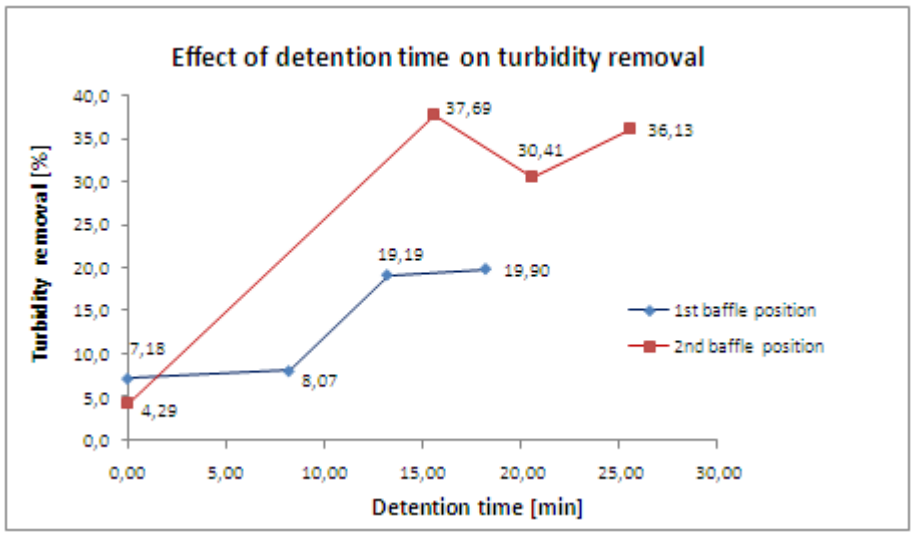


Fig. 4.22 Comparison of the first baffle position and the second for Qair = 10% Qin without adding chemicals

- For Q_{air} = 15% of Q_{in}

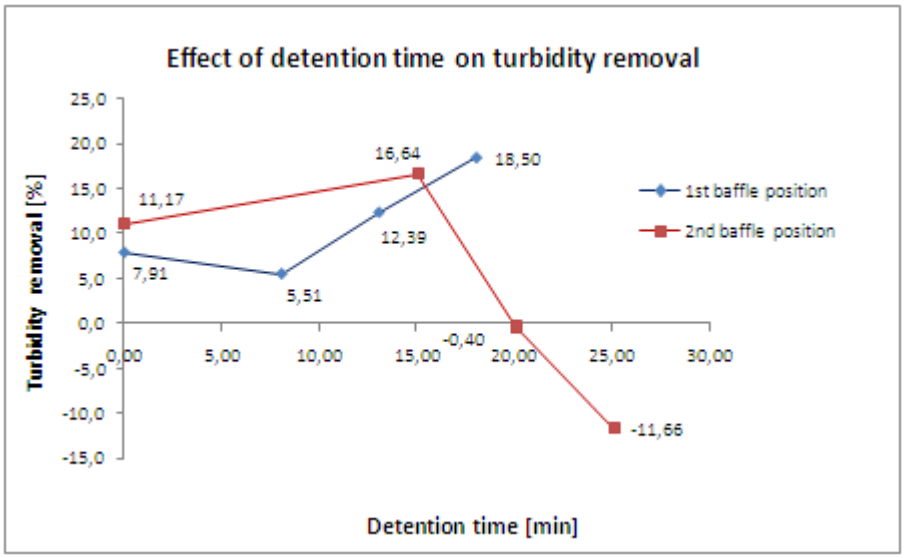


Fig. 4.23 Comparison of the first baffle position and the second for Qair = 15% Qin without adding chemicals

- For Q_{air} = 20% of Q_{in}

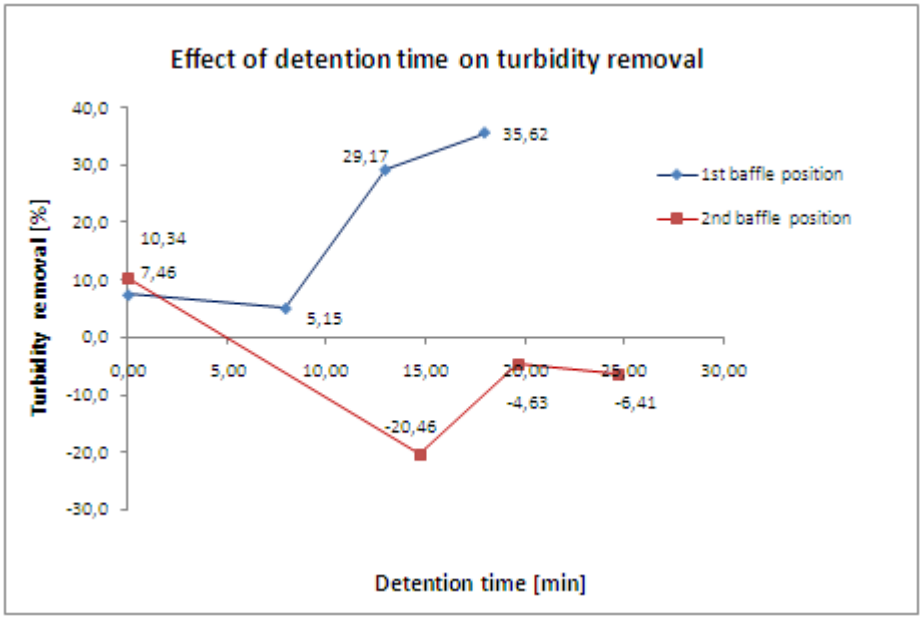


Fig. 4.24 Comparison of the first baffle position and the second for Qair = 20% Qin without adding chemicals

4.4.3 MEASURING WITH ADDING CHEMICALS

As acceptable chemicals for this test were chosen PAX 18 in concentration 1 : 5 (PAX 18 : pure water) and with dosing 50 mg/L into raw water. PAX 18 is a high performance liquid polyaluminium chloride coagulant that generally offers superior clarification in either potable or wastewater. To its advantages belong reducing sludge, minimizing pH adjustment, longer filter runs, superior finished water quality and optimized cold water performance. So PAX 18 is a general-purpose coagulant, versatile enough to handle any type of challenge. It is composed of Aluminium (cca 9 %), Al_2O_3 (cca 17,1 %) and iron – Fe (< 0,01 %) [7].

For the pH adjusting was used sodium hydroxide NaOH to increasing pH and sulphurid acid H_2SO_4 to decreasing pH value . By the previous tests was determined that the most suitable pH value with the highest efficiency of PAX 18 is 6,2. So, pH value for this test was being adjusted to this value - 6,2 by the help of adding NaOH and H_2SO_4.

Results for the first baffle position with adding chemicals

Results for the *first baffle position* are illustrated in the table (4.6) below.

Tab. 4.6 Results for the first baffle position with adding chemicals

Results for the 1st baffle position (A_1 =0,04m^2 a V_1 =0,024m^3)

	Detention time in contact z.	$l_{sep.z.}$ [cm]	Detention time in sep. zone	Total detention time	pH [-]		Turbidity [NTU]			UV absorbance [1/M]		
					1*	2*	1*	2*	%	1*	2*	1*-2*
Q_{air}[10%]	3min 12s	-	0	0	6,12	6,38	4,53	4,19	7,51	23,60	6,68	16,92
		7,5	5min	8min 12s	6,16	6,37	4,63	2,67	42,33	23,60	7,20	16,40
		15,0	**10min**	**13min 12s**	**6,15**	**6,10**	**5,57**	**2,62**	**52,96**	23,40	8,04	15,36
		22,4	15min	18min 12s	6,19	6,29	5,62	2,69	52,14	21,80	7,74	14,06
Q_{air}[15%]	3min 4s	-	0	0	6,71	6,43	2,20	2,18	0,91	2,22	-13,00	15,22
		7,5	5min	8min 4s	6,16	6,43	2,31	1,32	42,86	2,03	-12,00	14,03
		15,0	10min	13min 4s	6,29	6,22	3,64	2,53	30,49	0,90	-9,50	10,40
		22,4	15min	18min 4s	6,32	6,78	3,74	2,65	29,14	-0,50	-9,40	8,90
Q_{air}[20%]	2min 56s	-	0	0	6,35	6,41	2,80	2,64	5,71	-3,20	-11,00	7,80
		7,5	5min	7min 56s	6,16	6,42	2,97	2,20	25,93	-3,30	-11,00	7,70
		15,0	10min	12min 56s	6,24	6,49	3,20	2,23	30,31	-4,70	-11,00	6,30
		22,4	15min	17min 56s	6,25	6,41	3,28	2,10	35,98	-5,90	-11,00	5,10

1* ...raw water
2* ... water after flotation
% ... percentage of removal

pH. The pH value of raw water (column 1*) should be adjusted approximately to value 6,2. It´s not possible to keep exact value all the time, so the values above are commonly usable.

Turbidity. The effect of turbidity removal is generally higher with adding chemicals than the turbidity removal without adding chemicals. Below, in chapter 4 „Conclusion“ are shown charts with comparison of turbidity removal without using chemicals and with using them. One of many factors influencing effectivity is turbidity amount in raw water. Hold generally, higher turbidity amount in raw water, can be cause of higher flotation efficiency. For this case is the best amount of percentage removal 52,96 % for Q_{air} = 10% of Q_{in} and $l_{sep.z.}$= 15 cm. It can be possible, that the results are different from supposals because of factors influencing flotation.

UV absorbance. The effectivity of UV absorbance is clearly much higher with adding chemicals than without adding them. Although the efficiency is decreasing with increasing detention time and Q_{air}, UV absorbnance removal is still very high unlike for the case without adding chemicals.

Courses of functions are represented in charts below (Fig. 4.25; 4.26).

Chart: Effect of detention time on turbidity removal

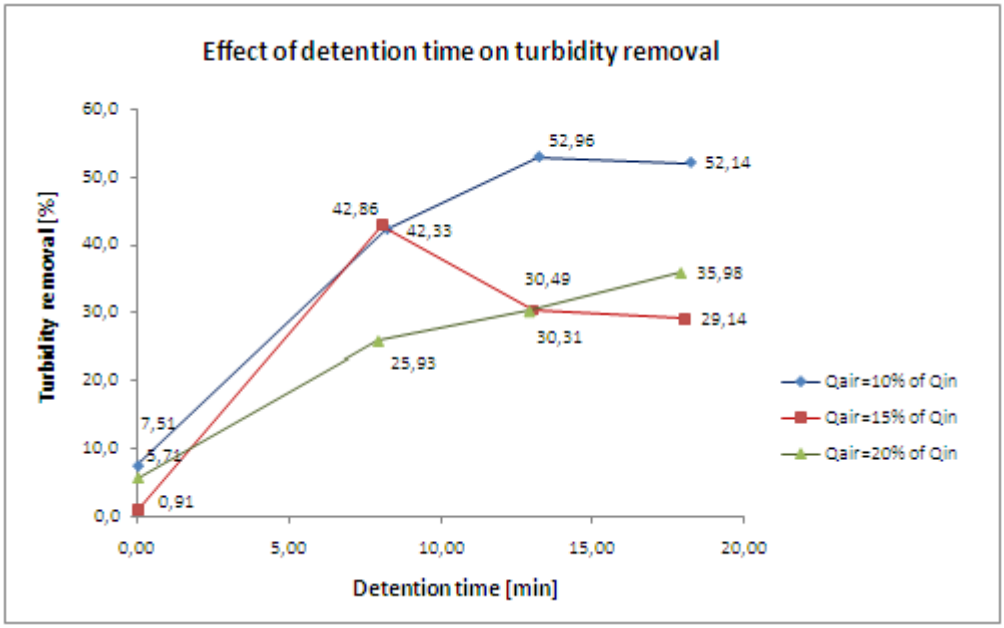


Fig. 4.25 Comparison of different air flow (Qair) for the first baffle position with adding chemicals

Chart: Effect of detention time on UV absorbance removal

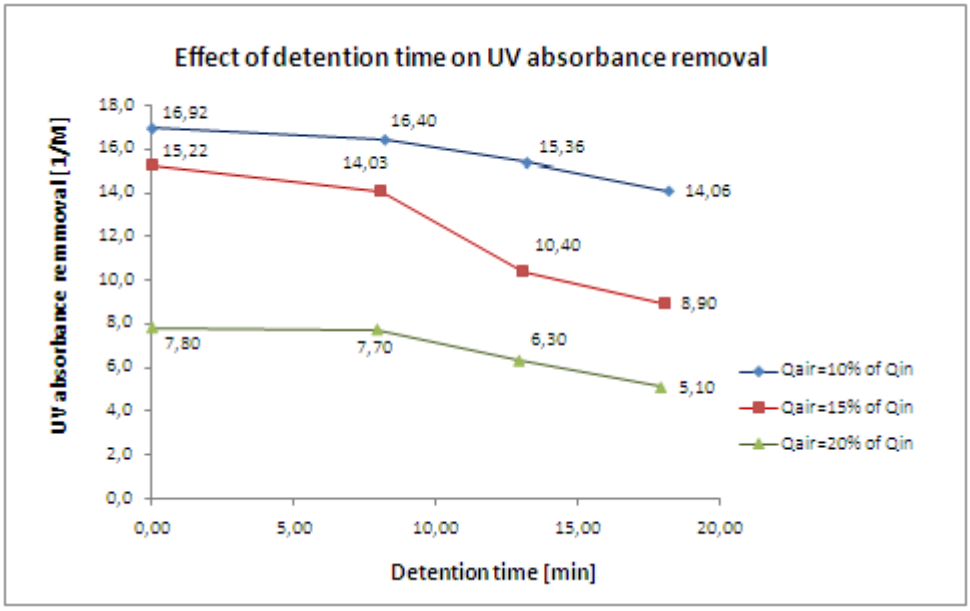


Fig. 4.26 Comparison of different air flow (Qair) for the first baffle position with adding chemicals

Charts above (Fig. 4.25; 4.26) represent courses of functions for effect of detention time on turbidity removal (Fig. 4.25) and on UV absorbance removal (Fig. 4.26) for different Q_{air} with adding chemicals and for the *first baffle position*.

Results for the second baffle position with adding chemicals

Table below (4.7) demonstrates results (effectivity of tubidity and UV removal) for the *second baffle position* with adding chemicals.

Tab. 4.7 Results for the second baffle position with adding chemicals

Results for the 2nd baffle position (A_2=0,08m^2 a V_2=0,077m^3)

	Detention time in contact z.	$l_{sep.z.}$ [cm]	Detention time in sep. zone	Total detention time	pH [-]		Turbidity [NTU]			UV absorbance [1/M]		
					1*	2*	1*	2*	%	1*	2*	1*-2*
Q_{air}[10%]	10min 32s	-	0	0	6,36	6,51	2,59	2,38	*8,11*	-6,90	-13,00	*6,10*
		7,5	5min	15min 32s	6,32	6,52	2,70	1,43	*47,04*	6,99	0,15	*6,84*
		15,0	10min	20min 32s	6,21	6,49	2,92	1,75	*40,07*	5,60	0,65	*4,95*
		22,4	15min	25min 32s	6,27	6,50	3,03	1,87	*38,28*	4,83	0,42	*4,41*
Q_{air}[15%]	10min 5s	-	0	0	6,29	6,58	3,95	3,62	*8,35*	4,40	-0,30	*4,70*
		7,5	**5min**	**15min 5s**	**6,20**	**6,55**	**3,80**	**1,90**	***50,00***	4,34	-0,10	*4,44*
		15,0	10min	20min 5s	6,20	6,52	4,05	2,23	*44,94*	3,26	0,33	*2,93*
		22,4	15min	25min 5s	6,27	6,46	3,91	2,47	*36,83*	2,88	0,61	*2,27*
Q_{air}[20%]	9min 39s	-	0	0	6,32	6,68	3,90	3,74	*4,10*	2,72	0,61	*2,11*
		7,5	5min	14min 39s	6,22	6,57	4,12	3,65	*11,41*	0,03	-2,40	*2,43*
		15,0	10min	19min 39s	6,23	6,39	3,40	2,37	*30,29*	-0,70	-2,60	*1,90*
		22,4	15min	24min 39s	6,25	6,39	2,85	2,08	*27,02*	-1,00	-2,30	*1,30*

1* ...raw water
2* ...after flotation
% ... percentage of removal

pH. The pH value of raw water (column 1*) in this case has the same conditions as for the first baffle position, respectively that the pH should be adjusted approximately to value 6,2.

Turbidity. As was written before, the effectivity of turbidity removal is generally higher with adding chemicals than the turbidity removal without adding chemicals and depends on many factors. For this case is the best amount of percentage removal 50,00 % for Q_{air} = 15% of Q_{in} and $l_{sep.z.}$= 7,5 cm.

UV absorbance. The effectivity of UV absorbance is clearly much higher with adding chemicals than without adding them as it was noticed above.

Course of functions are represented in charts below (Fig. 4.27; 4.28)

Chart: Effect of detention time on turbidity removal

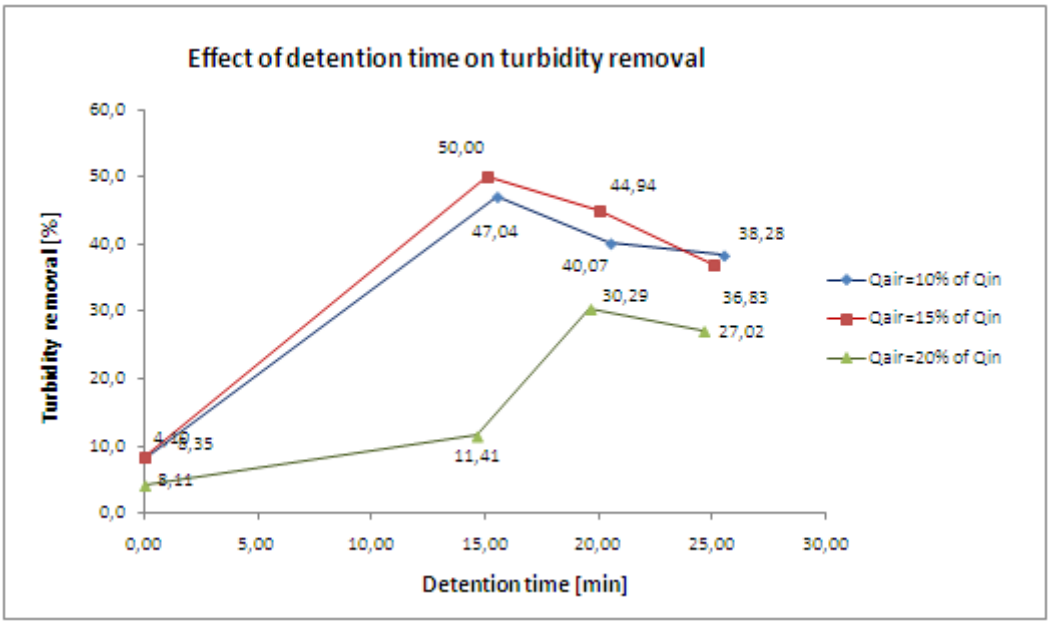


Fig. 4.27 Comparison of different air flow (Qair) for the second baffle position with adding chemicals

Chart: Effect of detention time on UV absorbance removal

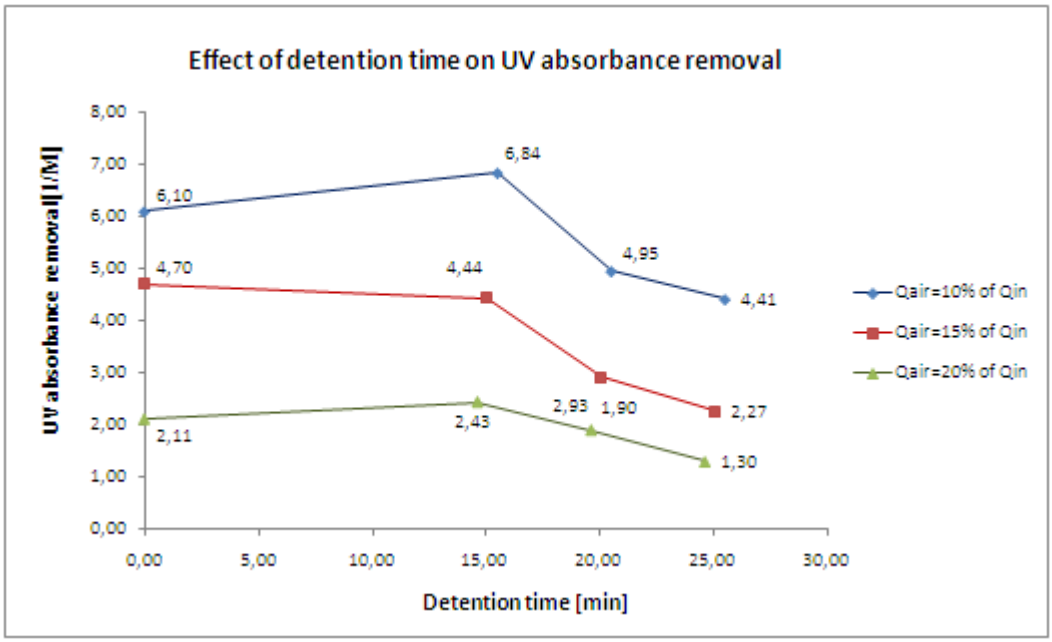


Fig. 4.28 Comparision of different air flow (Qair) for the second baffle position with adding chemicals

Charts above (Fig. 4.27; 4.28) represent courses of functions for effect of detention time on turbidity removal (Fig. 4.27) and on UV absorbance removal (Fig. 4.28) for different Q_{air} with adding chemicals and for the *second baffle position*.

Effectivity comparison first baffle position with second one for the case with adding chemicals

Effect of detention time on turbidity removal

The follow charts (Fig. 4.29; 4.30; 4.31) display *effect of detention time on turbidity removal* for flotation. There are illustrated comparisons of effect *between first and second baffle position* for different Q_{air} *with adding chemicals*.

- For Q_{air} = 10% of Q_{in}

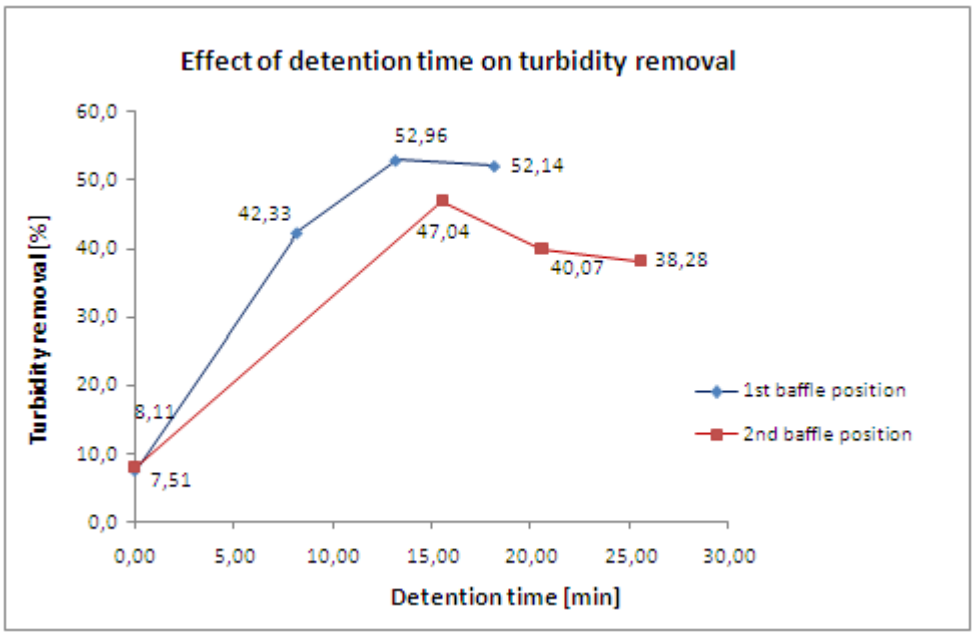


Fig. 4.29 Comparison of the first baffle position and the second for Qair = 10% Qin with adding chemicals

- For Q_{air} = 15% of Q_{in}

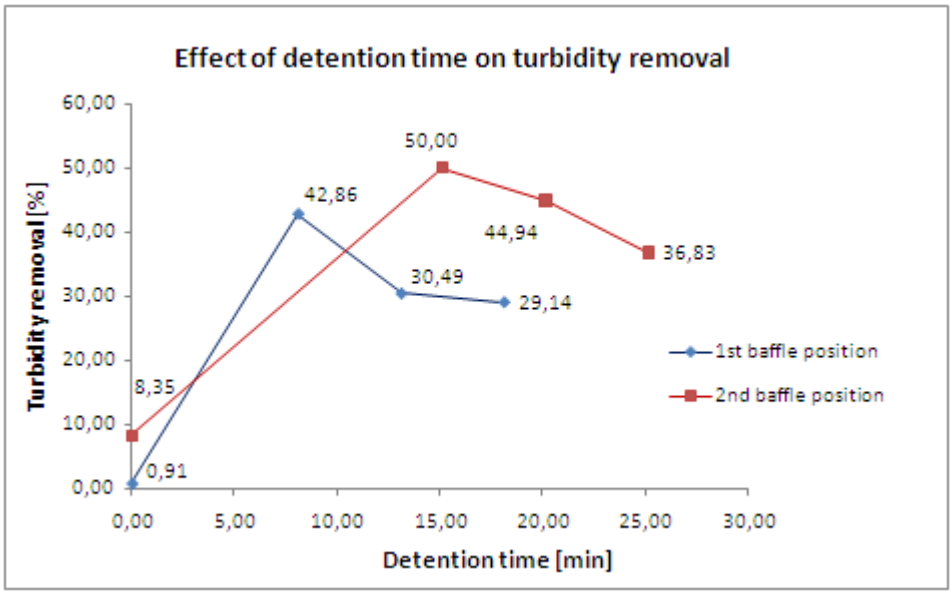


Fig. 4.30 Comparison of the first baffle position and the second for Qair = 15% Qin with adding chemicals

- For Q_{air} = 20% of Q_{in}

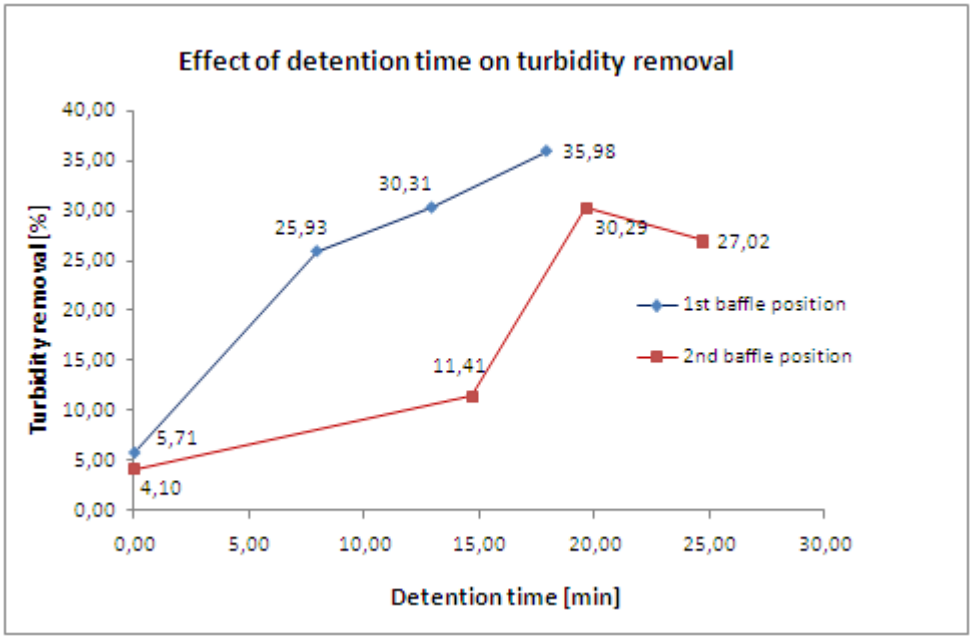


Fig. 4.31 Comparison of the first baffle position and the second for Qair = 20% Qin with adding chemicals

Effect of detention time on UV absorbance removal

The follow charts (Fig. 4.32; 4.33; 4.34) represent *effect of detention time on UV absorbance removal* for flotation with adding chemicals.

- For Q_{air} = 10% of Q_{in}

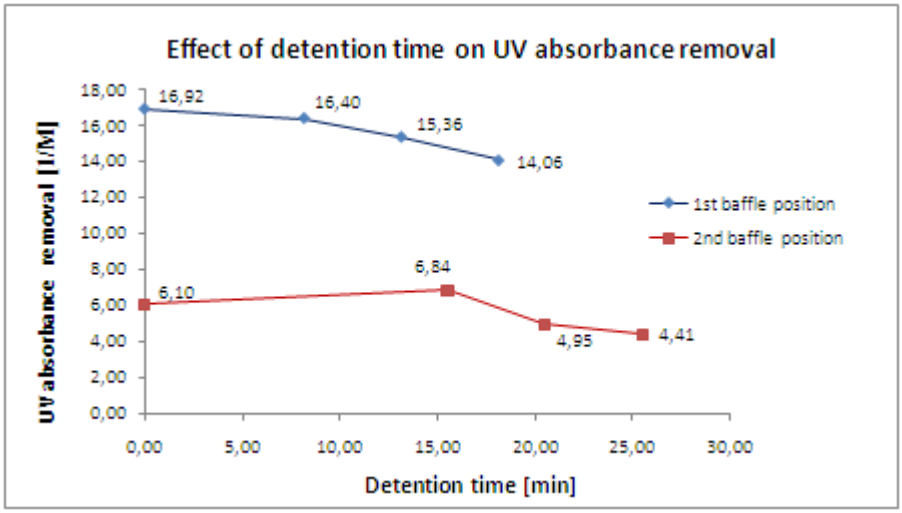


Fig. 4.32 Comparison of the first baffle position and the second for Qair = 10% Qin with adding chemicals

- For Q_{air} = 15% of Q_{in}

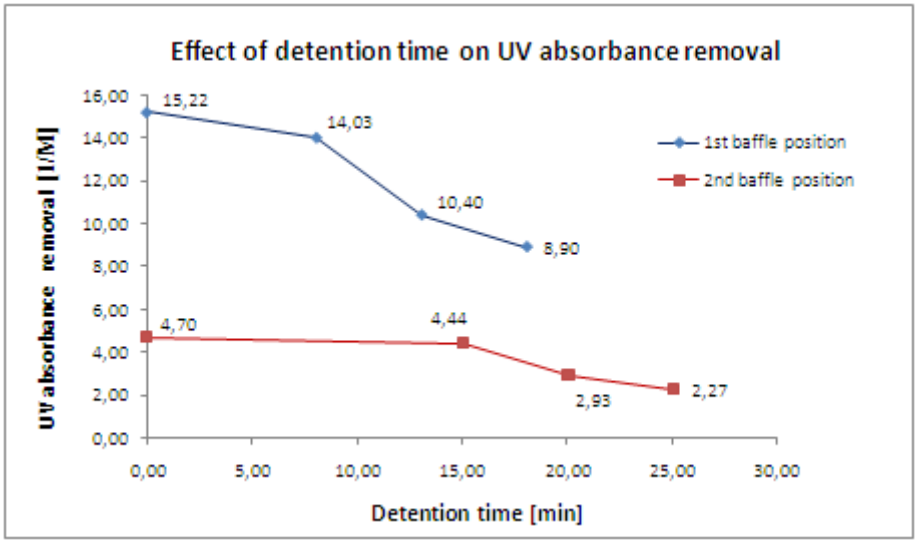


Fig. 4.33 Comparison of the first baffle position and the second for Qair = 15% Qin with adding chemicals

- For Q_{air} = 20% of Q_{in}

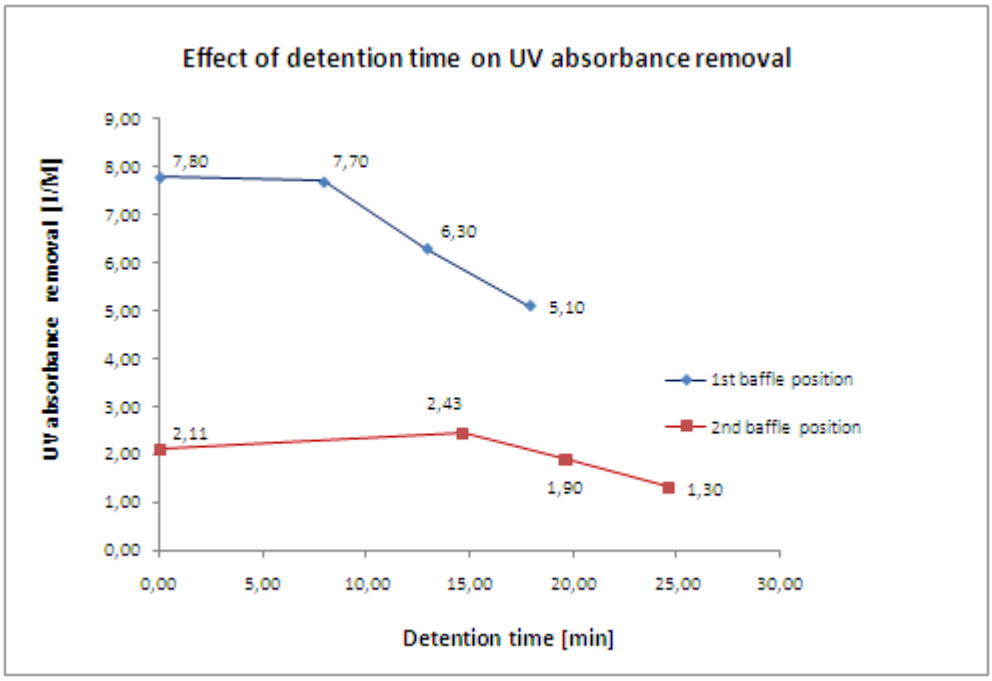


Fig. 4.34 Comparison of the first baffle position and the second for Qair = 20% Qin with adding chemicals

From charts (Fig. 4.29; 4.30; 4.31) is palpable, that the turbidity removal in comparison first and second baffle position is nearly similar for both cases. This is not true for UV removal (Fig. 4.32; 4.33, 4.34). The efficiency of UV removal is for the first baffle position much higher than for the second one. From this follow, that the smaller volume of contact zone is better choice for removing UV absorbance.

4.4.4 EFFECTIVITY COMPARISON OF MEASURING WITHOUT ADDING CHEMICALS AND WITH ADDING THEM

In the end I´d like to refer efficiency differences of turbidity removal in the event of using chemicals, on the one hand and without using them, on the other hand. Once more are individual situations digestedly displayed in follow charts.

First charts (Fig. 4.35; 4.36; 4.37) are constructed for the first baffle position and charts (Fig. 4.38; 4.39; 4.40) show us results for the second baffle position. All charts confront only turbidity removal.

A) For the first baffle position

- Q_{air} = 10% of Q_{in}

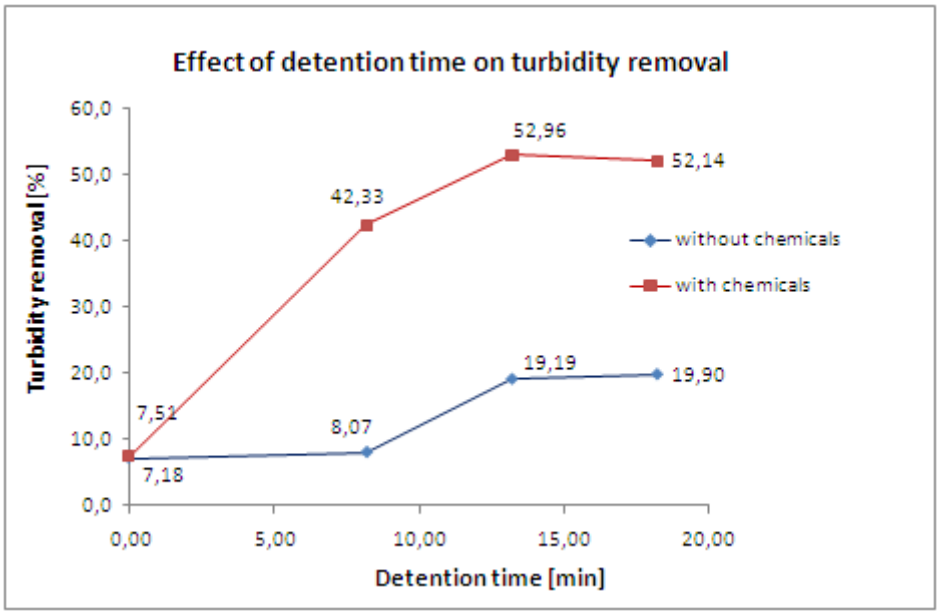


Fig. 4.35 Comparison of turbidity removal without adding chemicals and with adding them for Qair = 10% Qin

- Q_{air} = 15% of Q_{in}

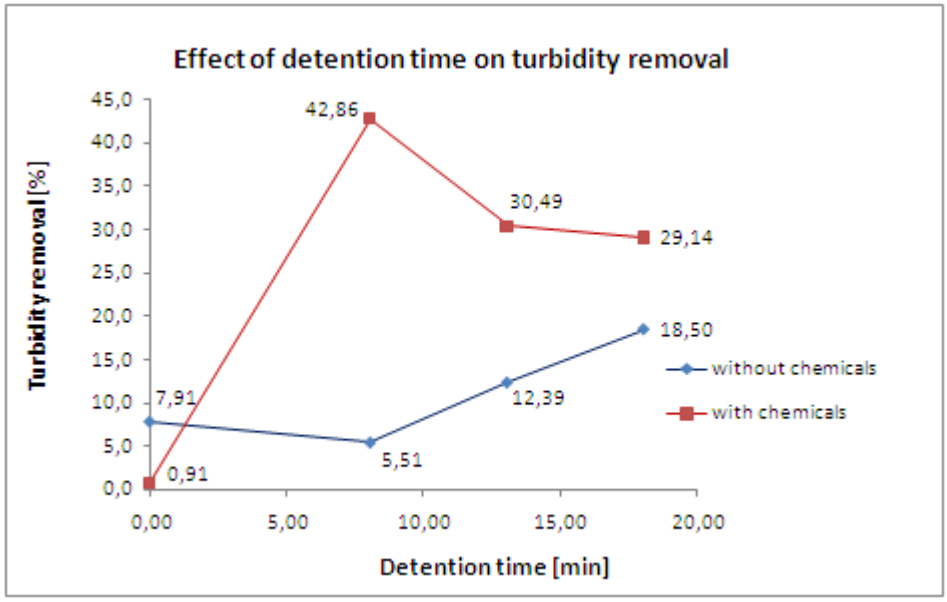


Fig. 4.36 Comparison of turbidity removal without adding chemicals and with adding them for Qair = 15% Qin

- Q_{air} = 20% of Q_{in}

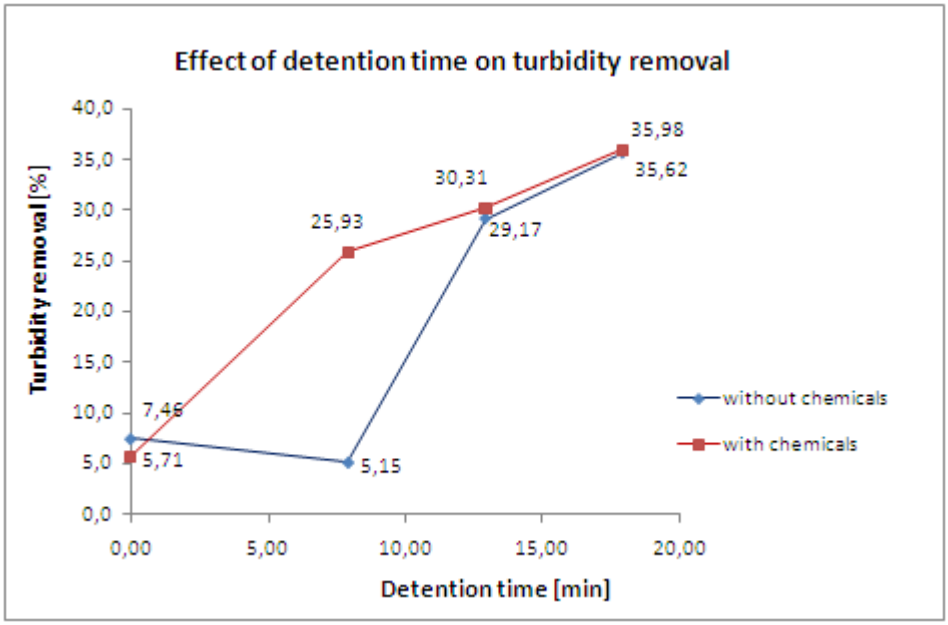


Fig. 4.37 Comparison of turbidity removal without adding chemicals and with adding them for Qair = 20% Qin

B) For the second baffle position

- Q_{air} = 10% of Q_{in}

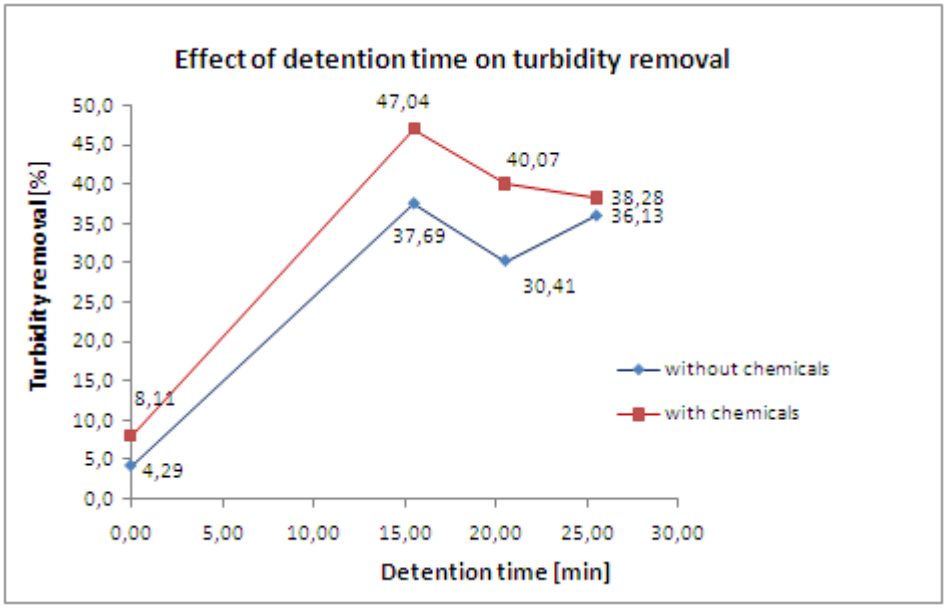


Fig. 4.38 Comparison of turbidity removal without adding chemicals and with adding them for Qair = 10% Qin

- Q_{air} = 15% of Q_{in}

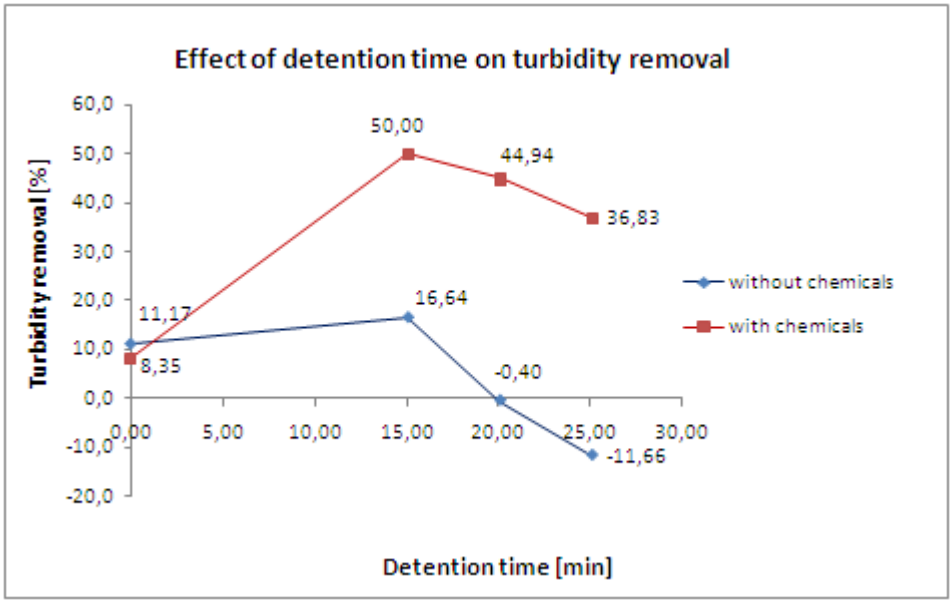


Fig. 4.39 Comparison of turbidity removal without adding chemicals and with adding them for Qair = 15% Qin

- Q_{air} = 20 % of Q_{in}

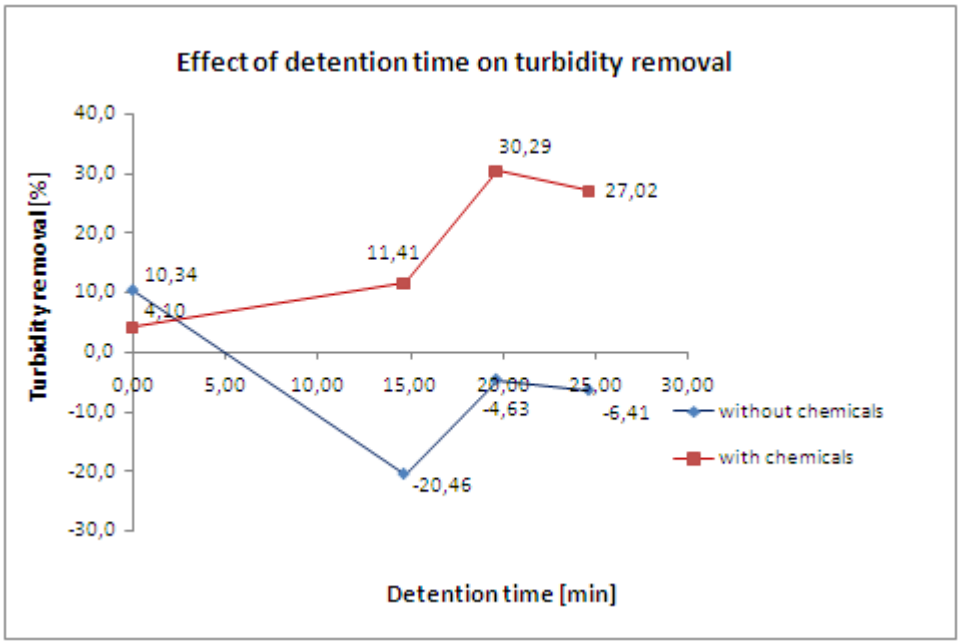


Fig. 4.40 Comparison of turbidity removal without adding chemicals and with adding them for Qair = 20% Qin

4.4.5 EFFECTIVITY COMPARISON FOR CASES WITH THE SAME Qair

Charts below (Fig. 4.41, 4.42, 4.43) confront only turbidity removal.

- Qair = 10% of Qin

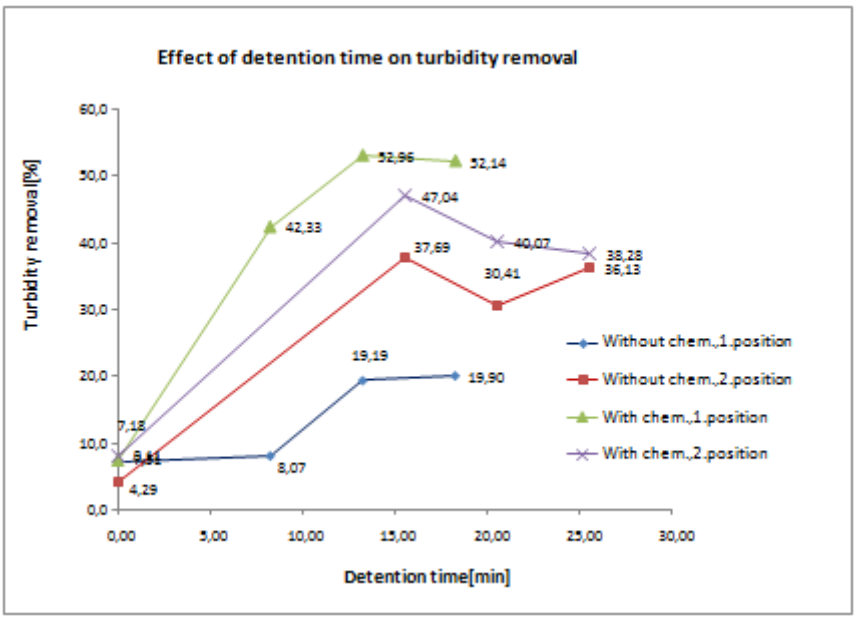


Fig. 4.41 Comparison of turbidity removal for Qair = 10% Qin

- Qair = 15% of Qin

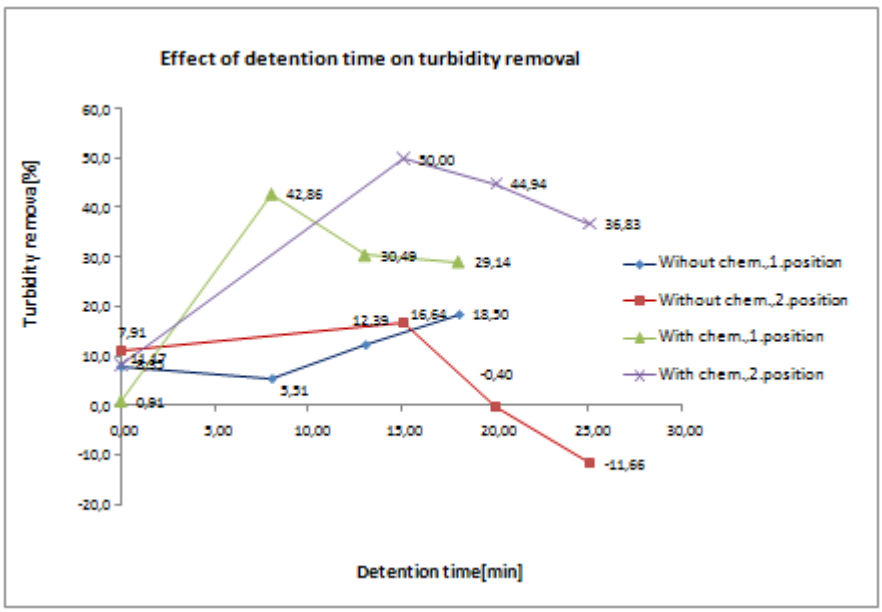


Fig. 4.42 Comparison of turbidity removal for Qair = 15% Qin

- Qair = 20% of Qin

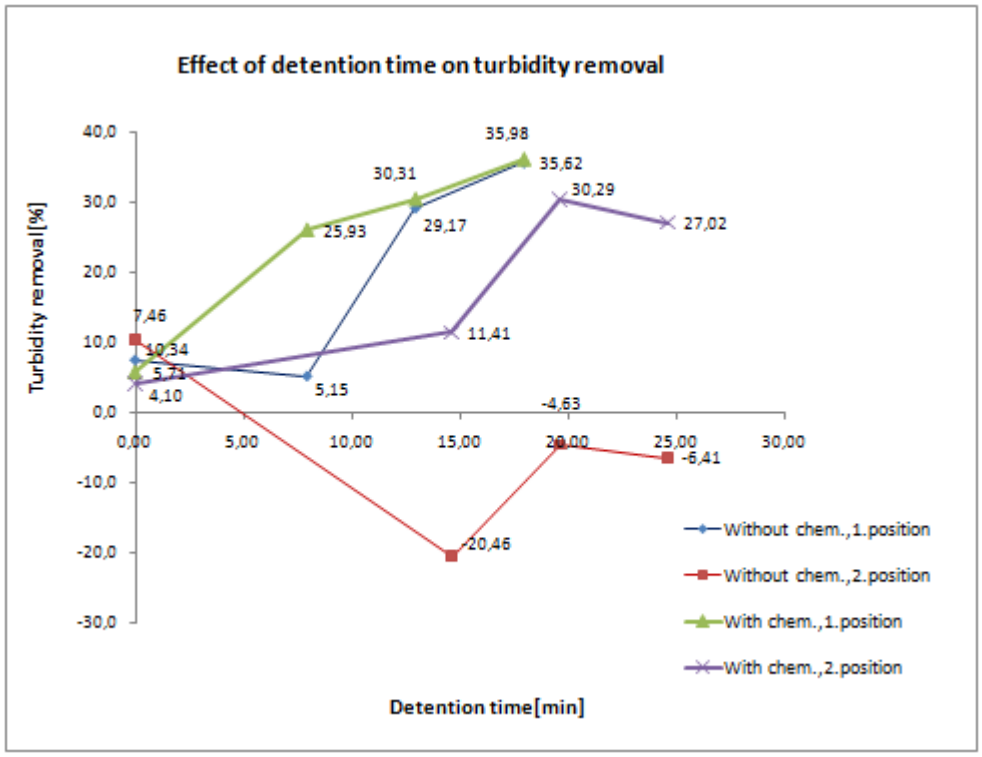


Fig. 4.43 Comparison of turbidity removal for Qair = 20% Qin

Mostly efficiency of turbidity removal is much higher for cases with using chemicals than without using them.

In few cases of this test is efficiency without adding chemical similar than with adding them. It happens because of factors influencing flotation efficiency, probably of factor raw water quality. As was mentioned above: hold generally, higher turbidity amount in raw water, can be cause of higher flotation efficiency. In all of these cases has the raw water in the event of without using chemicals almost three times higher turbidity than in raw water which wasn´t treated by the help of chemicals.

Generally we can say that for flotation efficiency is very important using chemicals to produce quality flocs, as well as we should respect other factors influencing flotation efficiency.

4.4.6 PHOTOS FROM LABORATORY OF FLOTATION PROCESS

Fig. 4.44 Flotation process without adding chemicals

Fig. 4.45 Float creation on the water surface (with adding chemicals)

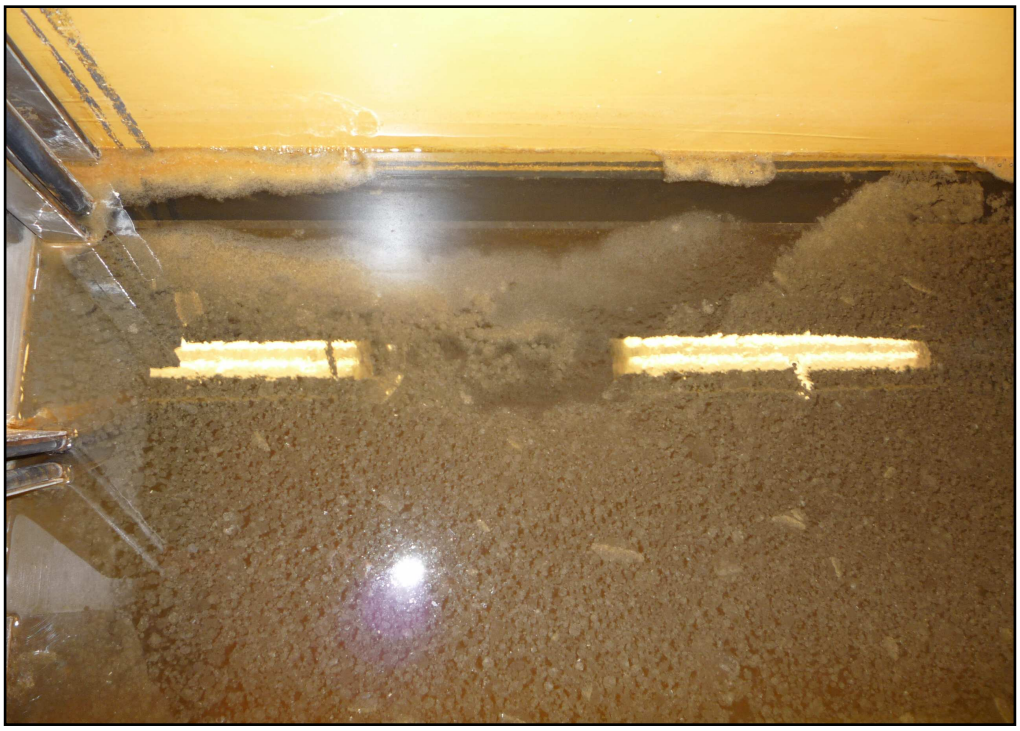


Fig. 4.46 Float created by the flotation process with adding chemicals

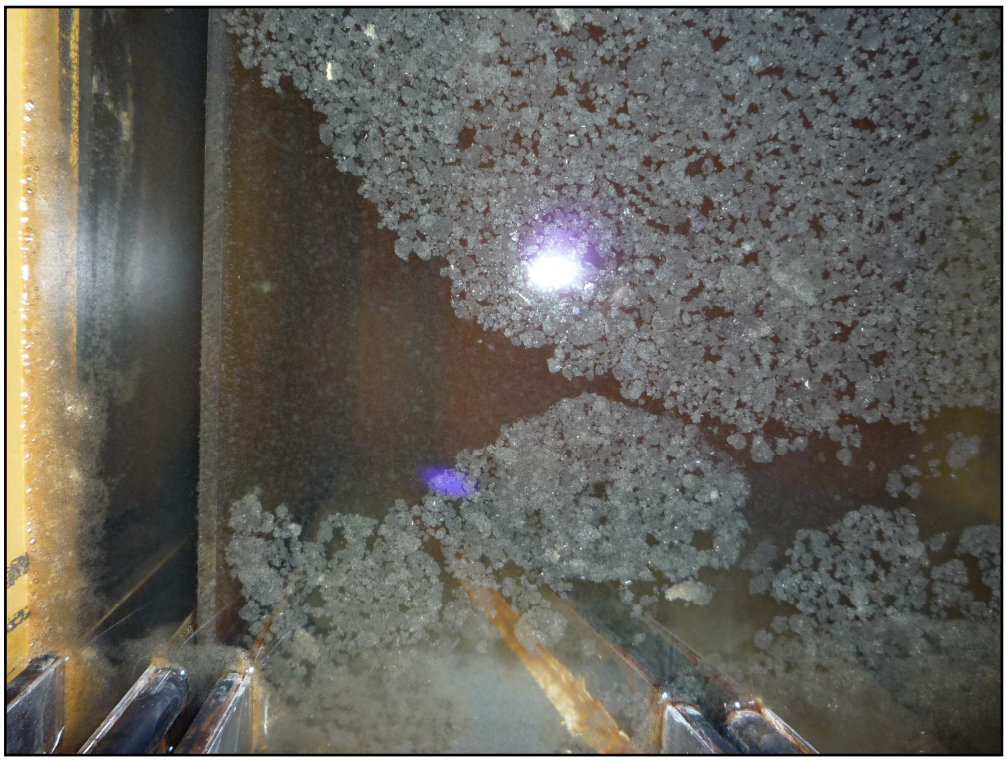


Fig. 4.47 Detail of buble-floc aggregations floating on the water surface

5 CONCLUSION

In this Master´s thesis is made model research on the efficiency of dissolved air flotation water treatment separation processes. Dissolved air flotation (DAF) is comparatively new process in water treatment. In Czech Republic is only one purification water treatment plant with DAF although it´s efficiency is sometimes more high than with using sedimentation. The reason why flotation is so little used can be low experiences with this process or more important thing, and that is because DAF needs energy to run. In North countries is DAF more commonly used water treatment process than in countries like Czech Republic.

Goal of this research was to recognize dissolved air flotation efficiency by the help of turbidity and UV absorbance removal in different conditions. As different conditions are meant the efficiency for different baffle position, different detention time in separation zone and checking results with adding chemicals compared to results without adding chemicals.

Conclusions of this thesis are that: Mostly efficiency of turbidity removal is much higher for cases with using chemicals than without using them. Chemicals help to create flocs, which together with bubbles float more easily to the water surface. Without using chemicals aren´t created flocs by particles, so it may not reached attachment of microbubble with particles.

In few cases of this test is efficiency without adding chemical similar than with adding them. It happens because of factors influencing flotation efficiency, probably of factor raw water quality. As was mentioned above: hold generally, higher turbidity amount in raw water, can be cause of higher flotation efficiency. In all of these cases has the raw water in the event of without using chemicals almost three times higher turbidity than in raw water which wasn´t treated by the help of chemicals.

Generally we can say that for flotation efficiency is very important using chemicals to produce quality flocs, as well as we should respect other factors influencing flotation efficiency. Flotation is more acceptable for purifying surface water low in absorbance and high in capacity of organic and humic substances. It is also suitable for removing fimbriae and cyanobacterias from eutrofic water.

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SEZNAM TABULEK:

SEZNAM OBRÁZKŮ:

SEZNAM POUŽITÝCH ZKRATEK A SYMBOLŮ:

DAF.....Dissolved air flotation

C_r ..... the mass concentration of air in the recycle flow [mg/L]

C_{fl} ..... the mass concentration of air in the floc tank effluent [mg/L]

r ..... is the recycle ratio expressed on a fractional basis [-]

p ..... pressure of the air [kPa]

C_{air} .....concentration of air dissolved in water [mg/L]

K_H ..... Henry´s law constant [kPa/mg.L^{-1}]

v_{pb} ..... the rise velocity of the floc particle-bubble aggregations (m/h)

g ..... gravitational constant of acceleration [m/s^2]

ρ_w ..... density of water [kg/m^3]

ρ_{pb} ..... density of the floc particle-bubble aggregations [kg/m^3]

d_{pb} ..... diameter of the floc particle-bubble aggregations

μ ..... absolute viscosity

l..... lenght [m]

b..... depth [m]

h_1 ..... height [m]

h_2 .....head of water [m]

Q.....flow [l/s]

Q_{in} ..... inflow [m3/h]

Q_{air} ..... air flow [m3/h]

Q_{out} ..... outflow [m3/h]

A_1..... area for the first baffle position [m2]

V_1..... volume for the first baffle position [m3]

A_2 ..... area for the second baffle position [m2]

V_2 ..... volume for the second baffle position [m3]

v_1 ..... hydraulic load in contact zone for the first baffle position [m/h]

T_1 ..... detention time in contact zone for the first baffle position [h]

v_2 ..... hydraulic load in contact zone for the second baffle position [m/h]

T_2 ..... detention time in contact zone for the second baffle position [h]

l_{5min} ..... separation zone length for detention time 5 min [cm]

l_{10min} ..... separation zone length for detention time 5 min [cm]

l_{15min} ..... separation zone length for detention time 5 min [cm]

SUMMARY:

This Master´s thesis is focused on model research on the efficiency of dissolved air flotation water treatment separation process. Flotation is technological process used in water treatment. It´s the reverse process of sedimentation, removing suspended particles which are lighter than surrounding water by gravitational rising [2].

In Czech Republic is only one purification water treatment plant with DAF although it´s efficiency is sometimes more high than with using sedimentation. The reason why can be low experiences with this process or more important thing and that is DAF needs energy to run. In North countries is DAF more commonly used water treatment process than in countries like Czech Republic. My opinion is we should more think about using flotation process. In several countries is DAF with effort commonly used in most purification water treatment plant.

At the beginning this thesis was described flotation process theoretically. This part contains ranking in conventional water treatment process, flotation history, types of flotation processes etc. Further was theoretical part more closely focused on dissolved air flotation (DAF) – types of flotation tanks, dissolved air flotation efficiency, factors influencing DAF efficiency, etc. At the end of this part is analysed comparison between sedimentation and DAF.

Next part imagines two examples of purification water treatment plants where is used DAF process. One of them takes place in the city of Oulu (Finland) and the second one, named Mostiště, is the only one purification water treatment plant with flotation process in Czech Republic.

Last part is focused on model research in laboratory of Oulu University. Firstly was described whole technological water treatment process updated with photos, after that are shown input data values, calculation, measuring, results evaluations and at the end are introduced results as comparison turbidity and UV absorbance removal for different conditions.

Conclusions of this thesis are that: Mostly efficiency of turbidity removal is much higher for cases with using chemicals than without using them. Chemicals help to create flocs, which together with bubbles float more easily to the water surface. Without using chemicals aren´t created flocs by particles, so it may not reached attachment of microbubble with particles.

In few cases of this test is efficiency without adding chemical similar than with adding them. It happens because of factors influencing flotation efficiency, probably of factor raw water quality. In all of these cases has the raw water in the event of without using chemicals almost three times higher turbidity than in raw water which wasn´t treated by the help of chemicals.

Generally we can say that for flotation efficiency is very important using chemicals to produce quality flocs, as well as we should respect other factors influencing flotation efficiency. Flotation is more acceptable for purifying surface water low in absorbance and high in capacity of organic and humic substances. It is also suitable for removing fimbriae and cyanobacterias from eutrofic water.